UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

OFFICE OF WATER

June 22, 2007

Dear Colleague:

Today we are making available the technical document "Options for the Expression of Daily Loads in TMDLs." This document was drafted to provide technically sound options for developing daily load expressions as a routine process in TMDLs calculated using allocation time frames greater than daily (e.g., annual, monthly, seasonal). The document is written for TMDL practitioners who are familiar with the relevant technical approach and regulatory requirements pertaining to TMDLs.

In November 2006 EPA issued the Memorandum "Establishing TMDL "Daily" Loads in Light of the Decision by the U.S. Court of Appeals for the D.C. Circuit in Friends of the Earth, Inc. v. EPA et. al., No. 05-5015 (April 25, 2006) and Implications for NPDES permits," which recommends that all TMDLs and associated load allocations and wasteload allocations include a daily time increment in conjunction with other appropriate temporal expressions that may be necessary to implement the relevant water quality standard. That Memorandum also indicated that additional technical information would be forthcoming, such as today's document.

Although this document is a draft, EPA intends that TMDL practitioners will make use of the technical information in developing TMDLs and provide feedback on the approaches as a result of their experience. Comments on the document should be sent to Rosaura Vega (vega.rosaura@epa.gov) and Mike Haire (haire.michael@epa.gov) by February 1, 2008.

Thanks again for your interest,

John Goodin /s/
Chief, Watershed Branch

Attachment

Copy of the document: "Options for Expressing Daily Loads in TMDLs."

For more information on this technical document, please refer to the above contacts or the appropriate Regional TMDL coordinator:

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Options for Expressing Daily Loads in TMDLs

U.S. Environmental Protection Agency

Office of Wetlands, Oceans & Watersheds

June 22, 2007

DRAFT

Disclaimer

This document provides technical information to TMDL practitioners who are familiar with the relevant technical approaches and legal requirements pertaining to developing TMDLs and refers to statutory and regulatory provisions that contain legally binding requirements. This document does not substitute for those provisions or regulations, nor is it a regulation itself. Thus, it does not impose legally binding requirements on EPA or States, who retain the discretion to adopt approaches on a case-by-case basis that differ from this information. Interested parties are free to raise questions about the appropriateness of the application of this information to a particular situation, and EPA will consider whether or not the technical approaches are appropriate in that situation.

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Acronyms

AnnAGNPS	Annualized Agricultural Nonpoint Source Pollution Model
BMP	best management practice
CAFO	concentrated animal feeding operation
CFR	Code of Federal Regulations
CSO	combined sewer overflow
CV	coefficient of variation
D.C.	District of Columbia
EMC	event mean concentration
EPA	U.S. Environmental Protection Agency
GWLF	Generalized Watershed Loading Functions
HSPF	Hydrologic Simulation Program—Fortran
ICPRB	Interstate Commission on the Potomac River Basin
LA	load allocation
LSPC	Loading Simulation Program in C++
LTA	long-term average
MDL	maximum daily limit
MOS	margin of safety
MS4	municipal separate storm sewer system
NPDES	National Pollutant Discharge Elimination System
PCB	polychlorinated biphenyls
SWAT	Soil and Water Assessment Tool
SWMM	Storm Water Management Model
TAM	Tidal Anacostia Model
TMDL	total maximum daily load
TSD	Technical Support Document
TSS	total suspended solids
USGS	U.S. Geological Survey
WASP	Water Quality Analysis Simulation Program
WLA	wasteload allocation
WQBEL	water quality-based effluent limit
WQS	water quality standard

Executive Summary

This document was produced to provide technical information to developers of total maximum daily loads (TMDLs) in light of the District of Columbia (D.C.) Circuit Court of Appeals decision in *Friends of the Earth, Inc. v. EPA, et al.*, No. 05-5015 (D.C. Cir. 2006), in which the D.C. Circuit held that two TMDLs for the Anacostia River (one established by U.S. Environmental Protection Agency [EPA] and one approved by EPA) did not comply with the Clean Water Act because they were not expressed as *daily* loads. As a result of the decision, EPA issued a memorandum entitled *Establishing TMDL "Daily" Loads in Light of the Decision by the U.S. Court of Appeals for the D.C. Circuit in Friends of the Earth, Inc. v. EPA et. al., No. 05-5015 (April 25, 2006) and Implications for NPDES Permits* in November 2006 that recommends that all TMDLs and associated load allocations (LAs) and wasteload allocations (WLAs) include a daily time increment in conjunction with other temporal expressions (e.g., annual, seasonal) that may be necessary to implement the relevant water quality standards.

This document was written to provide technically sound options for developing *daily load expressions* as a routine process in TMDLs calculated using allocation time frames greater than daily (e.g., annual, monthly, seasonal). It is written for TMDL practitioners—those individuals developing TMDLs who are familiar with relevant technical approaches and regulatory requirements. It is not intended to address issues associated with how to develop a TMDL; however, many of the issues presented are relevant to the task of TMDL development and, in light of the recommendation that TMDLs include a daily load expression, should be considered at the beginning of the development process.

Effect of Daily Loads on TMDL Development Methodologies

Including daily load expressions as a routine component in all TMDLs will require no fundamental changes in the way TMDLs are presently developed. In practice, TMDLs are developed for a variety of pollutants, environmental settings, pollutant source types, and waterbody types. They may be calculated using an assortment of analytical approaches and commonly use time steps ranging from daily to annual to express the loading capacity and associated allocations. In an effort to fully understand the physical and chemical dynamics of a waterbody, many TMDLs are developed using methodologies that result in identified allocations of monthly or greater time periods. EPA encourages TMDL developers to continue to apply accepted and reasonable methodologies when calculating TMDLs for impaired waterbodies and to use the most appropriate averaging period for developing allocations based on factors such as available data, watershed and waterbody characteristics, pollutant loading considerations, applicable standards, and the TMDL development methodology, among other things.

For a variety of reasons, EPA recognizes that it might continue to be appropriate and necessary to identify non-daily allocations in TMDL development despite the need to also identify daily loads. For parameters such as sediment, for which narrative water quality criteria often apply, attainment of WQS cannot always be judged on a daily basis. Assessment of cumulative loading impacts is necessary to understand how to achieve WQS and to estimate the allowable loading capacity; therefore identifying long-term allocations for such situations is appropriate and informative from a management perspective. For TMDLs in which it is determined that a non-daily allocation is more meaningful in understanding the pollutant/waterbody dynamics, EPA recommends that practitioners identify and include such an allocation, as well as a daily load expression with the final TMDL submission.

This document provides a description of the general process TMDL practitioners can use to develop daily load expressions, describes ways to obtain and develop additional data if necessary, describes the types of daily load expressions that can be used, discusses selection of daily load target value(s), and describes important factors to consider when determining what type of expression to use.

The recommended options are based on the following assumptions:

1. Methods and information used to develop the daily load should be consistent with the approach used to develop the loading analysis.
2. The analysis should avoid added analytical burden without providing added benefit.
3. The daily load expression should incorporate terms that address acceptable variability in loading under the long-term loading allocation. Because many TMDLs are developed for precipitation-driven parameters, one number will often not represent an adequate daily load value. Rather, a range of values might need to be presented to account for allowable differences in loading due to seasonal or flow-related conditions (e.g., daily maximum and daily median).
4. The methodologies provided in this document are applicable to a wide variety of TMDL situations; however, the specific application (e.g., data used, values selected) should be based on knowledge and consideration of site-specific characteristics and priorities.
5. The TMDL analysis on which the daily load expression is based fully meets the EPA requirements for approval, is appropriate for the specific pollutant and waterbody type, and results in attainment of water quality criteria.

Effect of Daily Loads on National Pollutant Discharge Elimination System Permits

EPA does not believe that the D.C. Circuit Court decision requires any changes in the way WLAs are currently implemented in National Pollutant Discharge Elimination System (NPDES) permits. Water quality-based effluent limits (WQBELs) in NPDES permits that implement WLAs in approved TMDLs must be "consistent with the assumptions and requirements of any available WLA for the discharge" (Title 40 of the *Code of Federal Regulations* [CFR] 122.44(d)(1)(vii)(B)). Note that these provisions do not require that effluent limits in NPDES permits be expressed in a form that is identical to the form in which the wasteload allocation for the discharge is expressed in a TMDL. Permit limits need only be "consistent with the assumptions and requirements" of a TMDL's wasteload allocation. States should continue to use existing guidance and policy memoranda to guide the development of WQBELs that are consistent with both 40 CFR 122.44(d)(1)(vii) and 40 CFR 122.45(d).

Additional Benefits of Daily Load Identification

For TMDLs in which long-term allocations are determined to be informative given the pollutant/waterbody dynamics, the daily load expression can additionally provide a tool for gauging whether load reductions are on track with meeting long-term TMDL allocations and, therefore, WQS. This is particularly useful when dealing with parameters for which no numeric criteria exist. Using post-TMDL monitoring data, observed loads can be calculated and compared to established daily load targets to determine progress in reducing watershed loads to levels required by the TMDL. It is important to note that for pollutants where the WQS has a longer than daily duration (e.g., monthly or seasonal average), individual values that are greater than the daily expression do not necessarily constitute an exceedance of the applicable standard.

Types of Daily Load Expressions

Conceptually, as shown in Figure E-1, the process for deriving daily loads for TMDLs typically based on non-daily allocations, builds on the data and information used in the non-daily TMDL analysis, supplementing that data as necessary and identifying a *daily load dataset*—a population of continuous or frequent allowable daily loads that meet the loading capacity and therefore represent maintenance of WQS. The daily dataset is then used to identify the daily load expression for the TMDL.

Depending on the approach used to develop the non-daily TMDL, the daily load dataset might be readily available or additional analysis might be needed. For example, when using a dynamic model with daily output or load duration curves, the daily load dataset is available as an output of the technique itself. Practitioners may select the daily load expression directly from the results of the analysis technique. However, when a technical approach results in longer term output (e.g., general watershed models and export coefficients), additional analysis (usually obtaining flow data) is required before the daily load dataset can be developed. This document provides options for supplementing typical non-daily TMDL analyses to develop the daily load dataset from TMDL approaches that result in longer term allocations.

Two basic options are available for presentation of daily loads. The first option is a static expression—a single daily load number or set of numbers applicable to all conditions in the waterbody. The second option is a variable expression that may be used when the applicable daily load value is determined as a function of a particular characteristic that affects loading or waterbody response, such as flow or season. Of these, the most common options will be targets that vary by flow (flow variable) and those that vary by month or by season (temporally variable). Because TMDLs are unique in nature, there is no specific format for presenting static or variable daily loads and the options presented in this document do not preclude variable targets based on other characteristics.

Selecting the appropriate type of daily load expression (static or variable) and the associated target value is driven by the characteristics of the waterbody for which the non-daily loadings are calculated as well as characteristics of the TMDL analysis used for the non-daily allocation. Factors such as data availability, assumptions made during the non-daily analysis, and time period addressed by the non-daily allocation may all affect the selection of the daily expression. When deciding, practitioners should take into account management implications, critical loading conditions, and pollutant sources and behavior while maintaining consistency with assumptions from the non-daily analysis. While TMDLs differ from one to the next, there are some general tendencies that can be used to guide selection of the appropriate daily load expression. Factors associated with specific parameters of concern provide limited direction as to the appropriate daily load option to use. Other considerations such as critical conditions and pollutant source types will be more indicative of the approach to use. Because of to the complexities of TMDL analysis, multiple critical considerations will affect how practitioners select the daily load option (static or variable) and the target value.

This document provides options for developing a daily load expression from a long-term allocation. It addresses selecting the appropriate averaging period or critical conditions for which the daily load value (or values) is protective. It shows illustrations of graphical and tabular options for identifying and presenting daily load options. A series of tables highlights the types of situations for which each daily load option might be appropriate depending on pollutant source type, critical condition, waterbody type, and so on. Finally, it presents a number of examples highlighting various approaches to identifying daily load expressions for long-term allocations for a variety of situations, parameters, and analytical methods.

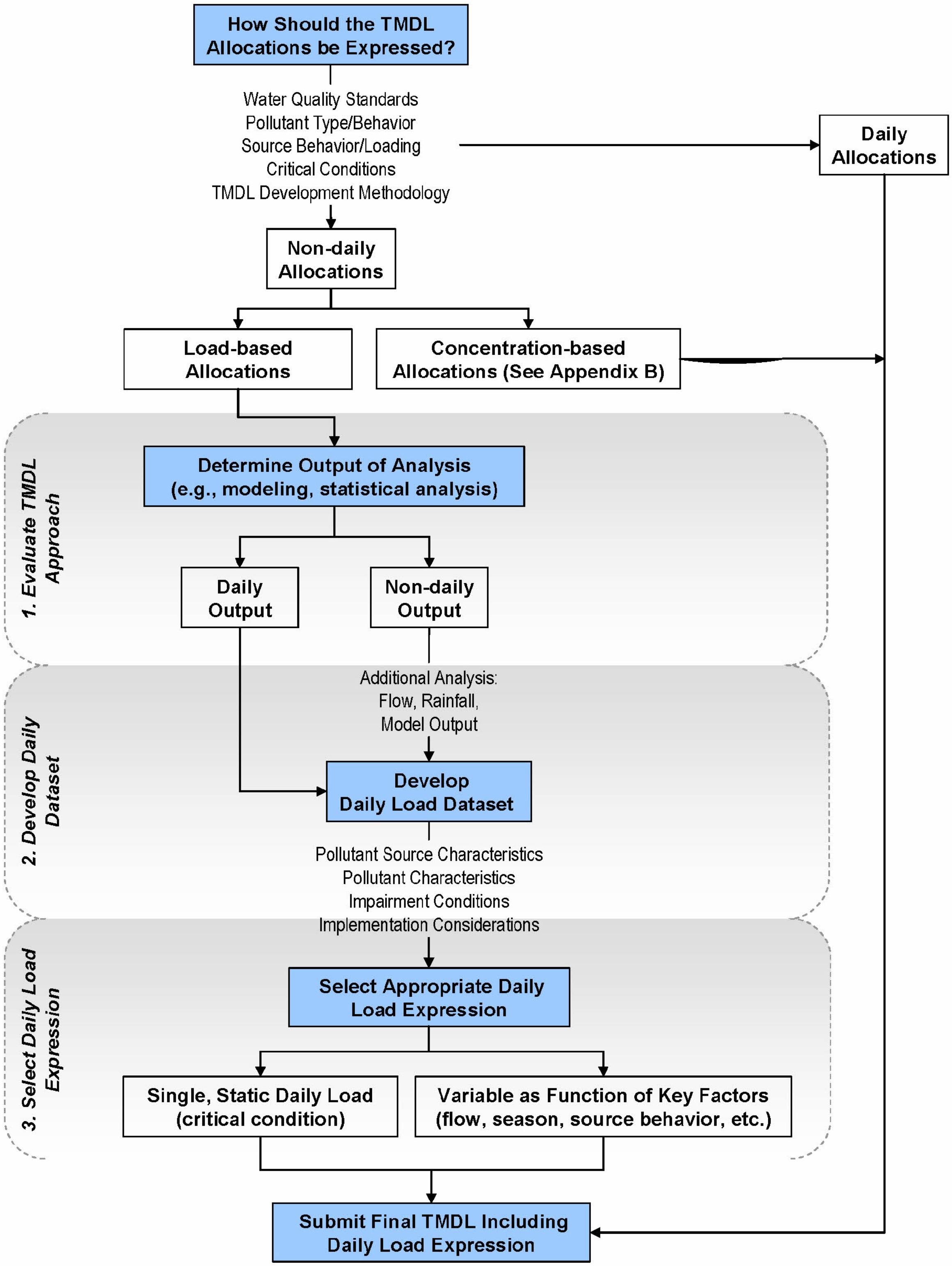

Figure E-1. Process for identifying daily load expressions from non-daily analysis.

Why Was this Document Developed?

Section 303(d) of the Clean Water Act requires that total maximum daily loads (TMDLs) be developed for all waterbodies for which controls are not stringent enough to meet applicable water quality criteria (Title 40 of the *Code of Federal Regulations* [CFR] Part 130). TMDLs are developed for a variety of pollutants, environmental settings, pollutant source types, and waterbody types. Depending on all these factors, TMDLs are calculated using a variety of analytical approaches and express allocations on timesteps ranging from daily to annual. For many TMDL pollutants, such as nutrients and sediment, primary threats to achieving water quality standards (WQS) can depend on cumulative load, and accuracy of pollutant loading estimates increases as the length of the calculation period increases. Therefore, establishing longer-term allocations is appropriate given the chronic nature of the pollutant loading and resulting impairments. Control of such pollutants is also best tracked when management measures are implemented and then monitored over a long-term period. For these reasons, many approved TMDLs have been expressed as maximum monthly, seasonal, or annual loads as opposed to daily loads.

> **For more information...**
>
> To read EPA's memo regarding development of daily loads in TMDLs, go to http://www.epa.gov/owow/tmdl/pdf/anacostia_memo111506.pdf

As a result of the recent D.C. Circuit Court of Appeals decision in *Friends of the Earth, Inc. v. EPA, et al.*, No. 05-5015 (D.C. Cir. 2006), EPA recommends that all future TMDLs and associated load allocations (LAs) and wasteload allocations (WLAs) also be expressed in terms of a daily time increment. While TMDL analytical approaches that result in longer (*non-daily*) averaging periods may continue to be used to demonstrate consistency with applicable water quality criteria, all final TMDL submissions should include an adequate expression of daily loads in addition to any longer-term loading expression that may be developed as a result of the TMDL analysis (USEPA 2006a). **The information presented in this document aims to help practitioners develop a daily load expression that is meaningful, useful and consistent with the analysis used to calculate the non-daily TMDL and corresponding loading capacity.**

Technical Background

Section 303(d)(C) of the Federal Water Pollution Control Act (the Clean Water Act) directs that TMDLs "shall be established at a level necessary to implement the applicable water quality standards with seasonal variations and a margin of safety." The accompanying regulations at 40 CFR 130.2 define the TMDL as "the sum of the individual WLAs for point sources and LAs for nonpoint sources and natural background." WLAs and LAs are defined as "portions of a receiving water's loading capacity," while loading capacity is defined as "the greatest amount of load that a water can receive without violating water quality standards." In essence, a TMDL is a strategy that meets the loading capacity and, thus, achieves WQS.

Loading capacity of most waterbodies is not constant in time. Depending on the constituent of concern, it can vary with stream flow, temperature, and many other variables. In some situations it makes sense to specify a constant maximum daily load that will result in achieving WQS under critical conditions (e.g., low flow) and all other conditions less stringent than the critical conditions. This type of approach is commonly used to develop permit limits for controlled effluent discharges such as wastewater treatment plants, but might be impractical for many nonpoint sources that vary naturally in response to precipitation and season.

There is no requirement that a daily load expression result in a single, constant daily load limit that is applicable to all situations, although this is one potential formulation. Rather, the maximum daily load(s) that are permissible are those that meet the loading capacity. As the loading capacity varies based on ambient conditions, so too may the maximum daily load that satisfies the loading capacity.

TMDLs that include time-variable loading limits are often generated by using a dynamic modeling technique, which can include both continuous simulation models and statistical approaches. EPA's *Technical Support Document for Water-quality Based Toxics Control* (USEPA 1991) (referred to as the TSD in this document) says, "Dynamic modeling techniques explicitly predict the effects of receiving water and effluent flow and of concentration variability… These methods calculate a probability distribution for RWCs [receiving water concentrations] rather than a single, worst-case concentration based on critical conditions… they determine the entire effluent concentration frequency distribution required to produce the desired frequency of criteria compliance." In other words, such models can be used to predict a stream's loading capacity and compliance with numeric criteria by calculating daily or even hourly flow and predicted concentrations, then relating them to numeric water quality criteria.

For other situations, the loading capacity is evaluated in terms of cumulative loads to achieve WQS. For instance, to achieve control of nuisance algal concentrations in a lake it might be most relevant to evaluate the cumulative phosphorus loading over the growing season rather than the load on individual days. In this situation, a model that demonstrates achieving WQS presents (explicitly or implicitly) a series of time-varying daily loads that achieves compliance.

In sum, while TMDLs should contain an expression of daily load, this daily load may be either a constant daily maximum load or a time-varying daily maximum load.

Expressing long-term LAs as daily loads can also be used to inform post-TMDL monitoring and tracking. While TMDL analyses might determine that an annual sediment load of 500 kg/year is consistent with meeting WQS and beneficial uses, without an understanding of when and how that 500 kg is delivered over the course of a year, it can be difficult to understand from routine water quality monitoring whether the TMDL is being met. Ideally, the process of translating a long-term load into a daily load can result in identifying expected variability in loads under a TMDL scenario. Monitoring data collected during a given sampling event can then be compared to the identified daily load values to evaluate whether the TMDL is being attained.

Document Purpose

The information in this document was developed recognizing that a significant portion of TMDLs will continue to be developed using analytical approaches that calculate long-term loading estimates (USEPA 2006a). To help states and Regions ensure that TMDLs also include a daily expression, methods are needed to derive daily expressions from non-daily loads calculated using common TMDL approaches. This document was developed to help satisfy that need.

Options for the derivation of daily loads are driven by:

- Characteristics of the original analysis
- Supporting data availability
- Source characteristics
- Critical loading period(s)

It is important to note that factors involved in TMDL development vary greatly from one analysis to the next. Such differences are related to waterbody type, watershed size, pollutants of concern, critical conditions, and available data, as well as to resources available for TMDL development including scheduling, available funds, and technical expertise. It is not possible to provide prescriptive instructions for translating loading expressions on the basis of specific waterbody types or pollutant types because there are simply too many possible combinations of pollutant/waterbody type/analytical techniques. In general, however, available translation options can be categorized on the basis of the characteristics of the original technical analysis and supporting data availability, as well as system characteristics such as pollutant type, active source types, and factors that define critical conditions. This document describes the general process for deriving a daily load from a non-daily load on the basis of TMDL analysis characteristics. It also identifies various graphical and tabular options for presenting the daily expression. Finally, the document discusses critical issues to consider in crafting an appropriate daily expression that acknowledges expected loading variability and is appropriate to the TMDL characteristics (e.g., pollutant, source).

Benefits of Including a Daily Load Expression in a TMDL

- Inform post-TMDL monitoring
- Act as an instantaneous measure to track water quality improvement
- Provide higher temporal resolution information to support implementation

This document is written for TMDL practitioners—those individuals developing TMDLs who are familiar with the relevant technical approaches and legal requirements. It is written to provide them with technically sound options for developing *daily load expressions* for ongoing or future TMDLs calculated using allocation time frames greater than daily (e.g., annual, monthly, seasonal). It is not intended to address issues associated with how to develop a TMDL; however, many of the issues presented are relevant to the task of developing TMDLs and, in light of the recommendation that TMDLs include a daily load expression, should be considered at the beginning of the development process. The recommended analytical approaches are based on the following basic assumptions:

1. Methods and information used to develop the daily load should be consistent with the approach used to develop the non-daily loading analysis.
2. The analysis should avoid added analytical burden without providing added benefit.
3. The daily load expression should incorporate terms that address acceptable variability in loading under the long-term loading allocation. Because many TMDLs are developed for precipitation-driven parameters, one number will often not represent an adequate daily load value. Rather, a range of values might need to be presented to account for allowable differences in loading due to seasonal or flow-related conditions (e.g., daily maximum and daily average).
4. The methodologies provided in this document are applicable to a wide variety of TMDL situations; however, the specific application (e.g., data used, values selected) should be based on knowledge and consideration of site-specific characteristics and priorities.
5. The TMDL analysis on which the daily load expression is based fully meets the EPA requirements for approval, is appropriate for the specific pollutant and waterbody type, and results in attainment of water quality criteria.

Document Organization

Section 1 provides an introduction to the three-step conceptual process for deriving daily load expressions from non-daily allocations. Typical technical approaches used for developing TMDLs are discussed along with typical outputs in relation to the three-step process. Section 2 provides options for using the non-daily analysis output to develop a daily load dataset necessary for identifying the daily load expression. In addition, the section outlines common problems and issues likely to be encountered by TMDL developers in the translation process and provides suggestions for how to handle them. Section 3 provides illustrations of graphical and tabular options for identifying and presenting daily load options and addresses the types of situations for which each might be appropriate. This section also provides guidance related to crafting the daily load expression, including selecting the appropriate averaging period or critical conditions for which the daily load value (or values) is protective. Appendix A contains a number of examples highlighting various approaches to converting long-term LAs to daily load expressions. Examples are presented for a variety of situations highlighting TMDLs developed for different parameters, using various analytical methods and applying different daily load expressions. Finally, Appendix B discusses an approach for identifying a daily expression for concentration-based TMDLs.

1. Process for Deriving Daily Load Expressions from Typical Non-daily TMDL Analyses

What Are the Goals of this Section?

- Introduce the conceptual process for deriving daily load expressions from typical non-daily analyses
- Illustrate the process with an example application
- Introduce concepts and critical issues that will be discussed in more detail in Sections 2 and 3

Whether TMDLs are expressed as daily allocations or non-daily allocations depends on such considerations as expressions of applicable WQS, pollutant type and behavior, source characteristics, critical conditions, and TMDL development methodology. If it is deemed appropriate to express a TMDL on a non-daily time frame, that non-daily TMDL should also include a daily expression. Conceptually, the process for identifying the appropriate daily load expression from a non-daily analysis is the same regardless of pollutant type, waterbody type, or source type. The process, illustrated in Figure 1, relies on capitalizing on the data and information used in the analysis, supplementing that data as necessary and identifying a *daily dataset*—a population of continuous or frequent allowable daily loads that meets the loading capacity and, therefore, represents maintenance of WQS. The daily dataset is then used to identify the daily load expression for the TMDL.

The first step in the process to identify the daily load expression, an evaluation of the technical approach to developing the non-daily load, provides the analyst with an understanding of what information is available for the process. If a model was used to develop the non-daily load, was the output on an hourly, daily, or monthly time step? Was another type of analysis used that perhaps was based on an assumption of a steady delivery of pollutant to the waterbody?

The second step results in the creation of the daily load dataset from which the daily expression will be created. In some cases, these data are produced from the non-daily load analysis (e.g., daily model output), while in others, these data must be developed through additional calculations.

While a wide variety of approaches are applicable to TMDL development, they can all be considered to result in analytical output of either subdaily/daily or greater than daily, regardless of how the TMDL allocations are expressed (daily, monthly, or annually). For example, dynamic watershed models (e.g., Hydrologic Simulation Program—Fortran [HSPF]) might produce simulated data on an hourly, daily, or monthly time step, while other methods such as loading coefficients might produce annual loading estimates. Understanding the technical approach used to develop the TMDL provides the ability to answer the first critical questions in the process to identify the daily load expression.

The third step involves working with the dataset to identify the most appropriate daily load expression on the basis of the practitioner's knowledge of the system. Once the daily load dataset is available, the exercise is one of selecting the *right* daily load expression. This will be determined by such factors as expression of the WQS, pollutant type and characteristics, pollutant source type and behavior, critical loading and impairment conditions, and implementation and monitoring plans. Daily load expressions can take a variety of forms, including dynamic daily loads that are dependent on environmental conditions (e.g., flow), temporally variable daily loads that establish static daily maximum loads for specific time periods, or a single, static maximum daily load for critical conditions or for all conditions.

A Note about Concentration-based TMDLs

The main sections of this document focus on TMDLs that support load-based allocations. For TMDLs that establish concentration-based allocations, information for identifying daily expressions is included in Appendix B.

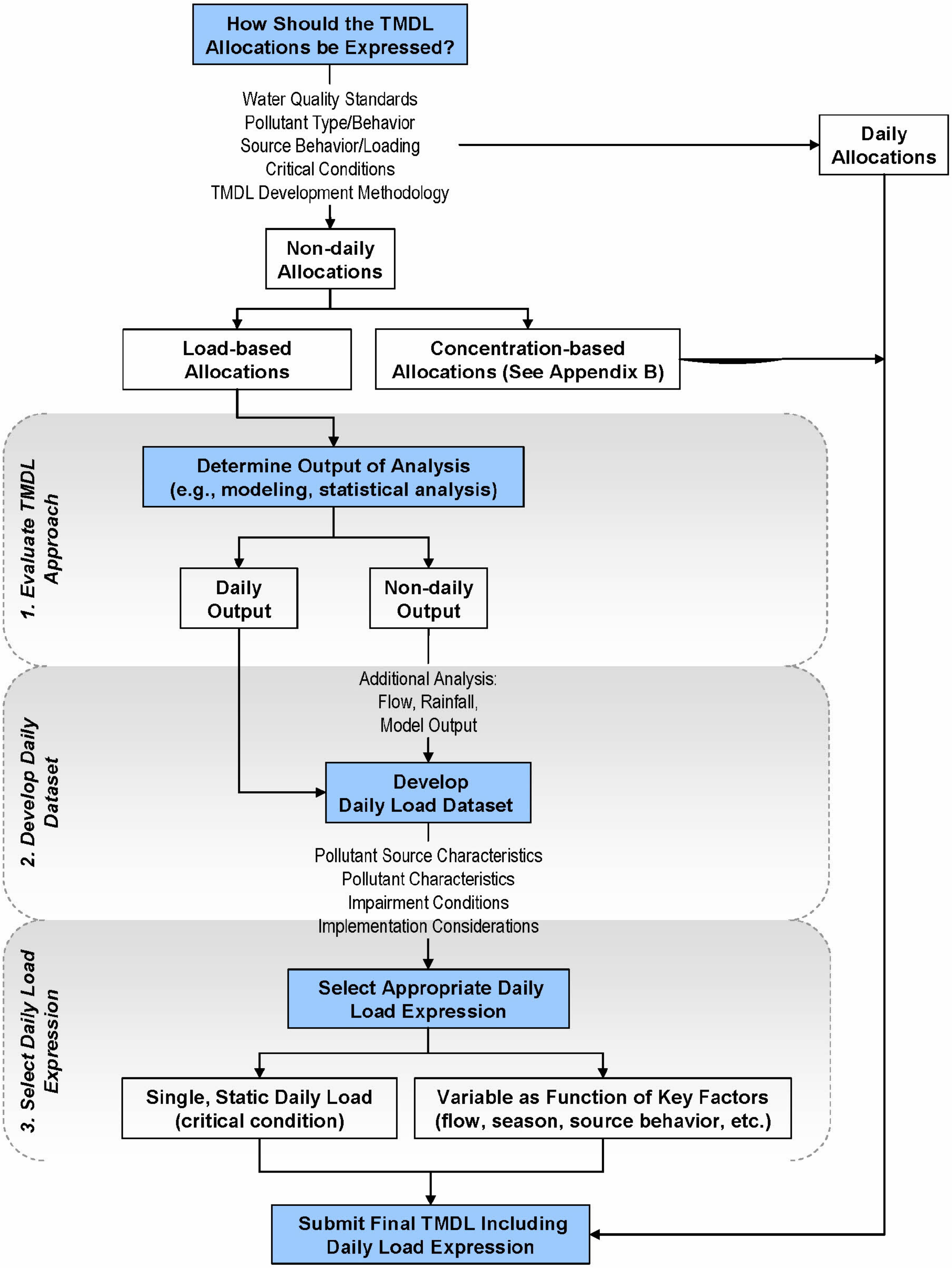

Figure 1. Process for identifying daily load expressions from non-daily analysis.

The daily load expression will provide an alternative or supplementary expression to the longer-term loading capacity and allocations established in the TMDL. Allocations based on monthly, seasonal, or annual timeframes are valuable components to guide management measures and implementation plans because they are related to the overall loading capacity of the waterbody, while the daily expressions represent day to day snapshots of the total loading capacity based on ambient conditions.

The daily expression can provide a useful tool for tracking the progress toward meeting the longer-term allocations and goals. Follow-up monitoring data can be compared with daily maximum loads to gather insight into how the waterbody is responding to implementation efforts and whether short-term loads and conditions are within the range of conditions represented by the longer term TMDL allocations. The daily expression of the TMDL supports and informs monitoring efforts and other implementation activities such as implementing best management practices (BMPs) and establishing permit limits.

Is One Number Enough?

In establishing a daily load expression for a non-daily TMDL, it will often be useful to identify a daily maximum and a daily average. Daily maximums are typically established to allow for infrequent, high-concentration inputs, while daily or monthly averages are provided to represent more consistent or persistent loading conditions. Identifying both a daily maximum load and some value representative of average conditions in non-daily TMDLs can represent the range of conditions that are acceptable on a daily basis and that will meet the overall TMDL allocations and, therefore, the applicable WQS.

Consider, as an example, a phosphorus TMDL established with seasonal LAs to meet an allowable in-stream concentration based on historical water quality data. The allocations were determined using a dynamic model providing daily output. The following provides a variety of loading values for the TMDL condition, including the original seasonal allocations and the corresponding maximum daily load, average daily load, and the 50th, 75th, and 95th percentile loads by season:

Example loads	Winter	Spring	Summer	Fall
Allocation: Seasonal load (kg/season)	370,080	247,860	191,700	229,230
Seasonal daily average (kg/day)	**4,112**	**2,754**	**2,130**	**2,547**
Seasonal daily maximum (kg/day)	153,504	86,680	121,561	171,456
Seasonal 50th percentile (kg/day)	324	433	101	121
Seasonal 75th percentile (kg/day)	3,010	1,651	589	1,012
Seasonal 95th percentile (kg/day)	**19,074**	**15,489**	**10,954**	**11,141**

Suppose the daily load expression specified a single, maximum daily load set at the 95th percentile load for each season. If the daily maximum were reached (but not exceeded) every day, the maximum would be satisfied, but it would be impossible to meet the total seasonal LA or the corresponding seasonal average. As a result, long-term loading would not be controlled to the extent required to meet WQS. Alternatively, if only a daily average load were established, it might be difficult to gauge the importance of infrequently high loads to the overall LA—especially in situations with infrequent monitoring data. If monitoring is conducted only monthly and a load is measured that is well in exceedance of the daily average for that season, it would be difficult to gauge if that load were out of the range of acceptable values without having a daily maximum target for comparison. As a result, practitioners established the TMDL to include a maximum daily load using the 95th percentile load for each season along with an allowable daily average load for each season (shown in **bold**).

The process outlined in the flowchart presented in Figure 1 is further illustrated below with an example aluminum TMDL for the Smith River. The example takes an existing TMDL developed with a long-term approach and examines what would be needed to incorporate a daily load. Issues associated with each step are highlighted with discussion and graphs. In addition to highlighting key concepts related to identification of the daily load expression, the Smith River example also provides context for the post-TMDL uses of the resulting daily load targets. (Sections 2 and 3 of this document provide further details related to application of each step—creating the daily load dataset and selecting target values).

Step 1. Evaluate Non-daily TMDL Approach

As shown in Figure 1, the first step in the process to identify a daily load expression for long-term allocations is to evaluate the TMDL approach and the available data and output. Important aspects of the TMDL for this example include the following:

- The TMDL for the Smith River was calculated using a continuous watershed model. As a result, model output provides simulated daily flow, concentration, and load.
- The initial TMDL calculation satisfies in-stream water quality criteria—in this case, an acute concentration of 0.75 mg/L aluminum.
- Allocations are presented as monthly loads based on the average allowable monthly loads over a 5-year simulation period. Allowable monthly loads are simply the total of the individual allowable daily loads within the respective month.
- The resulting time series of allowable daily loads is the result of various scenarios of load reductions from watershed sources (e.g., land uses, point sources). Reductions to modeled loads were applied iteratively until the time series of daily concentrations resulted in continuous attainment of all applicable criteria.

Figure 2 presents the available water quality and flow data for the Smith River in comparison to the acute criterion.

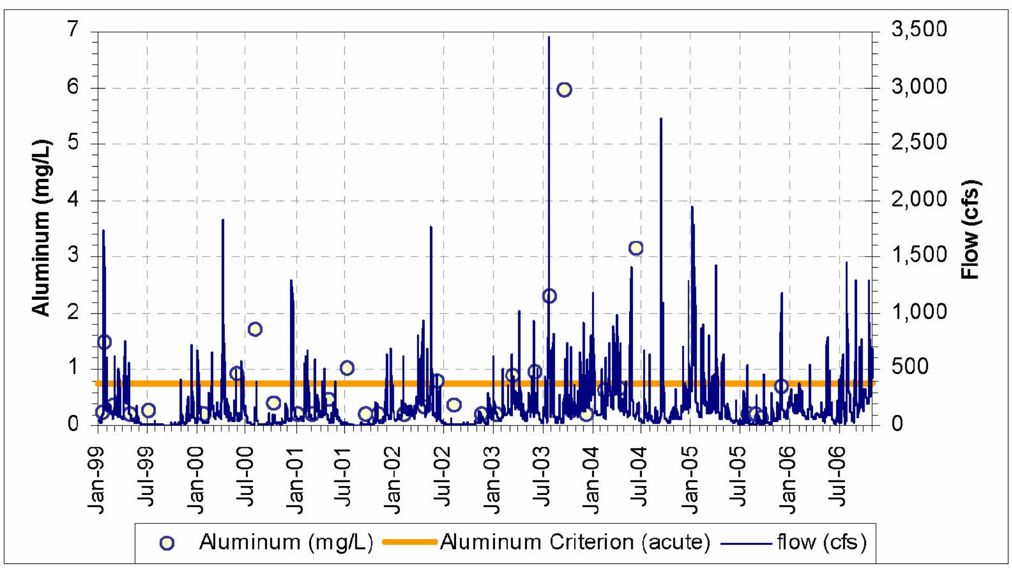

Figure 2. Example—observed water quality and flow data for Smith River.

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Step 2. Develop Daily Dataset

As illustrated in the process flowchart (Figure 1), the second step in identifying a daily load expression involves developing a daily load dataset from which the target(s) is selected. Because the model used to calculate the TMDL for the Smith River was a dynamic watershed model, the daily load dataset was obtained directly from the model output.

Figure 3 presents the time series of existing daily aluminum concentrations simulated by the watershed model, the corresponding daily flow, and observed aluminum concentrations. In Figure 4, modeled daily loads (modeled daily aluminum concentration multiplied by the modeled daily flow) under the TMDL condition are presented; the TMDL conditions represent a loading scenario under which all applicable water quality criteria are attained. This time series of allowable daily loads serves as the *daily load dataset* that is used to identify the daily load expression of the TMDL. Table 1 provides summary statistics of the daily load dataset, illustrating the magnitude and distribution of allowable daily loads.

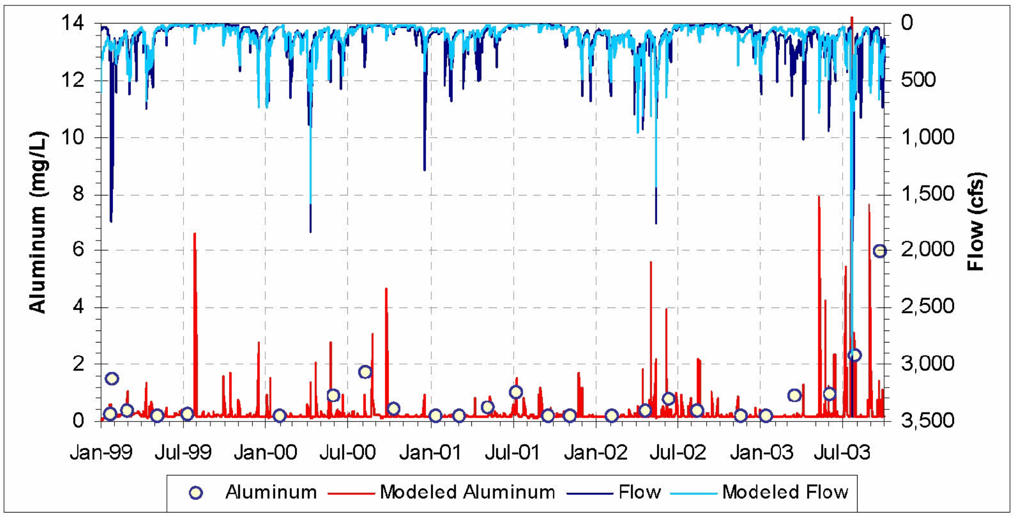

Figure 3. Daily time series under existing conditions for Smith River.

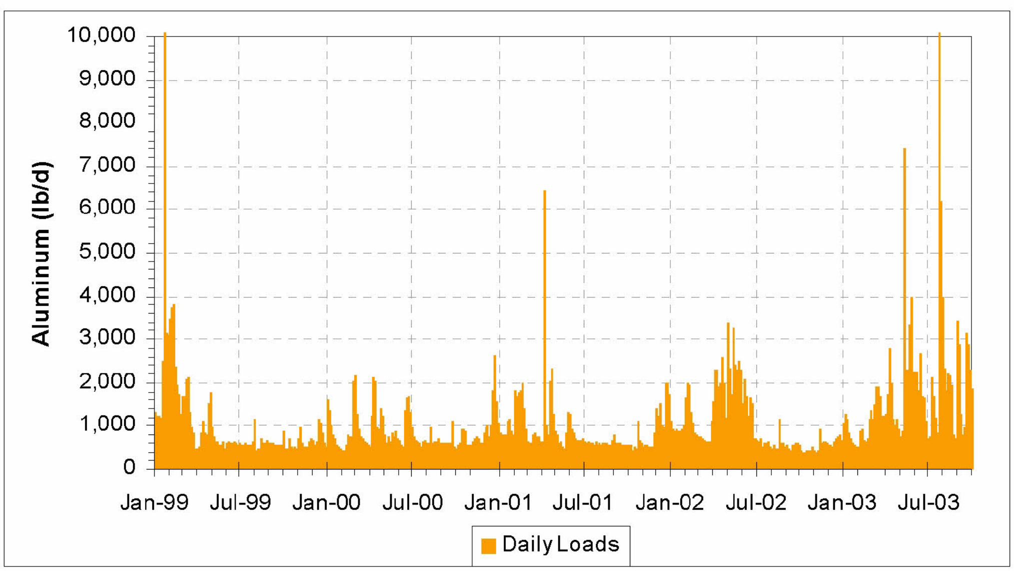

Figure 4. Modeled allowable daily loads under TMDL conditions for Smith River.

Table 1. Summary statistics of daily loads dataset

Statistic	Aluminum load (lb/day)
Minimum	367
25th percentile load	557
Median (50th percentile)	690
Average	968
75th percentile	1,090
Maximum	40,161

Step 3. Select Daily Load Expression

The final step of the process is to select the daily load expression that represents the longer-term TMDL allocations. To provide some perspective, it helps to think about how the identified load value will be used after the TMDL is implemented and what the resulting implications of each load would be. The maximum daily load can provide a tool for gauging whether load reductions are on track with meeting long-term TMDL allocations and, therefore, WQS. This is particularly useful when dealing with parameters for which no numeric criteria exist. Using post-TMDL monitoring data, observed loads can be calculated and compared to established daily load targets to determine progress in reducing watershed loads to levels required by the TMDL.

The level at which the target is established can affect its usefulness in evaluating follow-up monitoring and tracking progress. From Figure 4 and Table 1, it is evident that a very wide range of daily load values make up the total load under the TMDL scenario. Selecting, for example, the 50^{th} percentile load as the maximum daily load does not address the expected variation and ignores a significant portion of the loading capacity, and for management purposes, the target could be said to be too conservative. Using the median (i.e., 50^{th} percentile) load as the allowable daily maximum load, 691 lbs/day in the above example, essentially assumes that under the TMDL loading scenario (attaining applicable criteria), 50 percent of expected loads will exceed the allowable maximum.

There are a few points to consider in relation to setting the daily maximum. With a daily maximum load representing long-term allocations, there will be some exceedances that will occur while still maintaining the longer-term goals. Setting an appropriate target can diminish the effect of those exceedances on a manager's ability to confidently evaluate progress. If the target is set at the average or median daily allowable load, so many of the observed loads will exceed the average load that it will be difficult to gage at what point there is a problem and when conditions are not improving, or even worsening. The daily load expression could be set at a high percentile of the distribution, representing a value that should be rarely exceeded if the time series that represents the TMDL calculation is met. However, setting a target too high will also not be very informative. If the daily target is based on the maximum allowable load, by the time monitoring data exceed the target, there is likely already a problem.

For the *daily load target* to be both protective of WQS and informative for post-implementation monitoring, practitioners should identify a range of daily loads. At the very least, they should identify a daily maximum load or a daily average load in conjunction with the long-term average load established by the non-daily TMDL analysis. Ideally, both a daily maximum and daily average load will be identified in conjunction with the long-term allocation.

Figure 5 and Figure 6 help to illustrate the concept further. Figure 5 compares the time series of allowable daily loads to a maximum daily load target based on the 50th percentile load (691 lbs/day), while Figure 6 compares the daily loads to a maximum target based on the 95th percentile (2,182 lbs/day). Under TMDL conditions, one would see fewer exceedances when comparing loads to the 95th percentile target versus the 50th percentile target. However, setting the daily load expression at the 95th percentile will not in itself be protective of WQS unless the relationship of load to dilution capacity contained in the TMDL scenario is maintained.

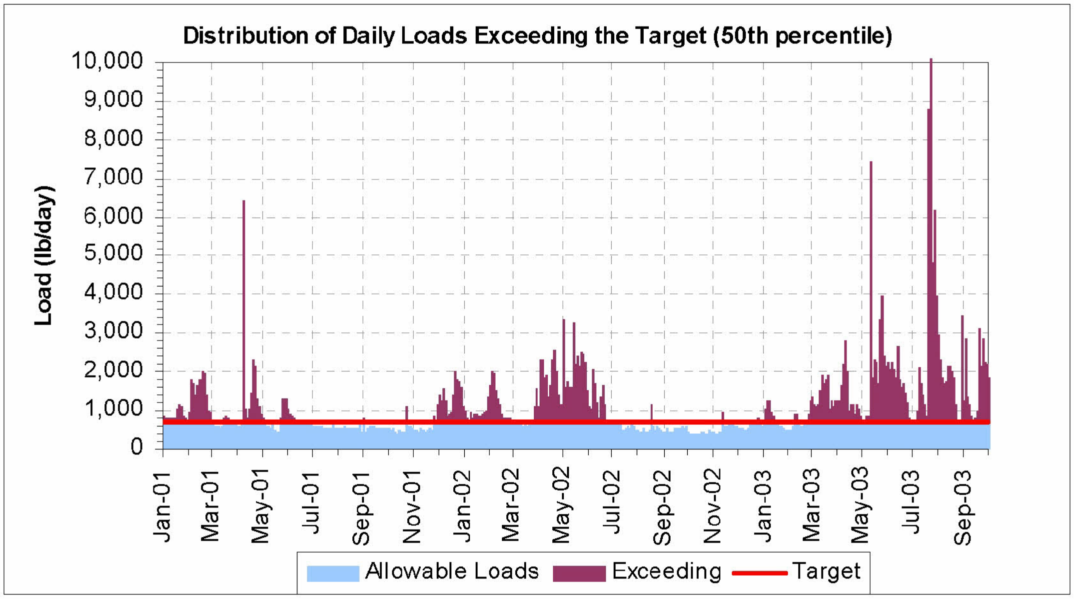

Figure 5. Example—comparison of daily loads to a daily maximum load target based on the median daily load.

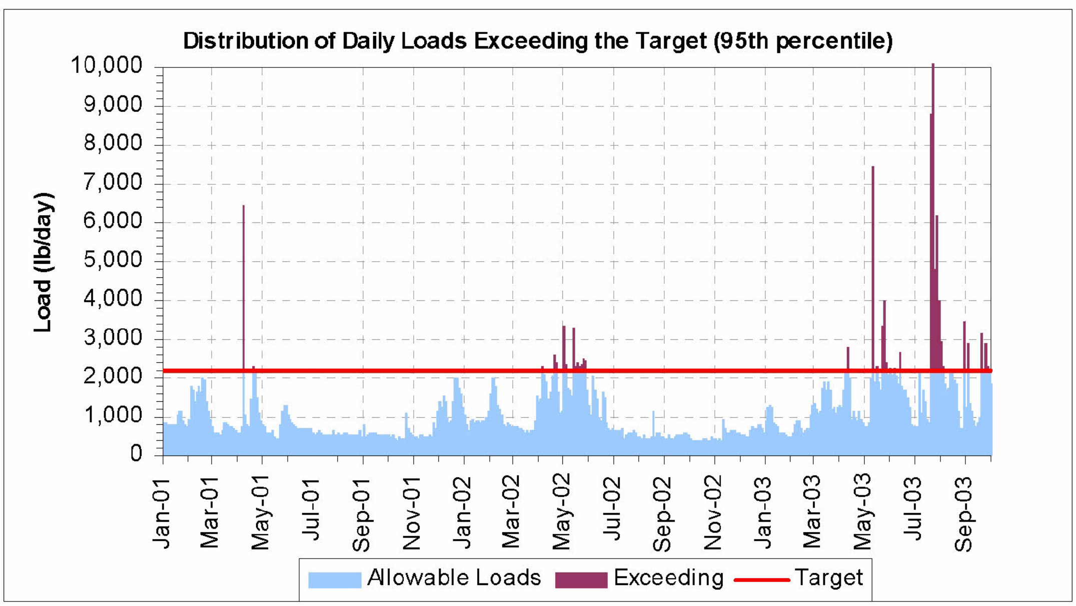

Figure 6. Example—comparison of daily loads to a daily maximum load target based on the 95th percentile daily load.

For monitoring purposes, using the 95th percentile load as a daily maximum value acts as a more effective *trigger*, indicating when conditions might be off track for meeting the longer-term goals of the TMDL. If monitoring data routinely exceed the 95th percentile load, it would be evident that loading reductions have not been sufficient to meet the TMDL. However, it is also important to recognize that using only a daily maximum target can mislead post-TMDL evaluation if used without longer-term targets. For example, if loads were as high as the 95th percentile value on a daily basis, loading conditions would far exceed the TMDL. The daily load target(s) should be expressed in such a way as to recognize average and extreme loads since both can occur while still maintaining the overall distribution of the *allowable* conditions represented by the TMDL analysis.

Therefore, for the Smith River, a dual target was established using the 95th percentile load as the daily maximum value to address variability in instantaneous concentrations and the 50th percentile load as the allowable daily median to represent long-term loading goals. Section 3 includes further discussion related to selecting specific daily load expressions.

Selecting the daily load target(s) can also be helpful in tracking post-TMDL implementation and water quality improvements. Monitoring conducted in the Smith River following implementation of the TMDL is shown in Figure 7. The graph compares observed pollutant loads to the daily maximum target (set as the 95th percentile allowable load). The observed data are also used to calculate a median daily load on the basis of on all previous samples; this median is compared to the supplementary daily target expressed as a median load. As shown in the figure, while monitoring data include some exceedances of the daily maximum load, the median target is still met, maintaining the overall distribution of the *allowable* conditions represented by the TMDL analysis. Without including both a *maximum* and *average* daily targets, it is difficult to evaluate post-TMDL monitoring to determine how observed conditions relate to TMDL conditions.

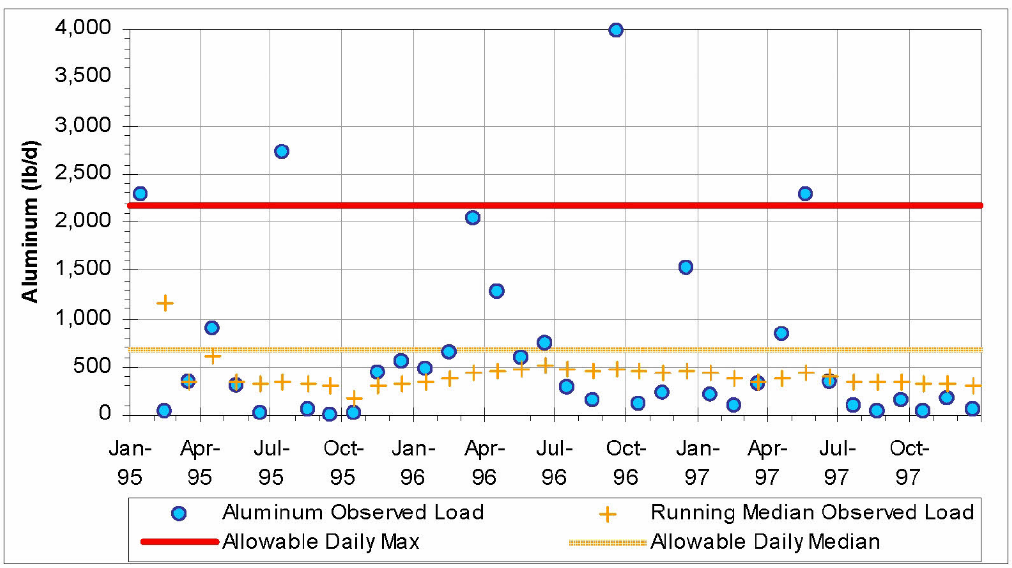

Figure 7. Example—comparison of post-TMDL monitoring to established daily targets.

The previous pages introduced several important issues in identifying daily load expressions for corresponding long-term TMDL allocations. The example illustrated key points related to crafting expressions that address expected variability in loading as well as identifying daily loads in a way that informs the post-implementation monitoring process. The next section provides greater detail regarding Step 2 of the process—creating the daily loads dataset.

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2. Developing a Daily Dataset from a Non-daily Analysis

This section discusses Step 2—Develop Daily Dataset—of the process to identify daily load expressions for non-daily analysis. This step is important to create a dataset that represents the variation and magnitude of allowable daily loads that result in attainment of long-term loading goals—a dataset from which the daily expression for the TMDL will be established. Whether the dataset is obtained directly from model output or is derived through additional analysis, it represents the distribution of daily loads under TMDL conditions. At its simplest, the dataset should be able to account for the basic variation of daily loads in relation to watershed conditions, such as relating loads that occur during wet periods with high flows and those occurring during dry periods with low flows.

What Are the Goals of this Section?

- Discuss how to create a *daily load dataset* based on typical TMDL analyses
- Review commonly used TMDL methodologies and their output
- Provide guidance for developing daily load datasets when supplemental analysis is required

This section provides guidance on generating the daily dataset from the following commonly used approaches for developing TMDLs:

- **Dynamic Model.** Many TMDLs use dynamic, time-variable watershed and receiving water models using daily or smaller time steps to establish the link between source loading and water quality response and to evaluate load reduction and management scenarios. These models provide continuous simulation of watershed and in-stream processes on the basis of a variety of inputs, including weather conditions, land use and other watershed characteristics, and waterbody characteristics (e.g., physical, chemical). Dynamic models can include watershed models (e.g., HSPF) or receiving water models (e.g., Water Quality Analysis Simulation Program [WASP]). Many dynamic watershed models also include an in-stream component that simulates in-stream fate and transport. While process, resolution, and detail vary greatly depending on the model used and the type of application, dynamic models typically provide daily or subdaily output for flow and loads.

- **Load Duration.** The load duration methodology relies on using observed flows and water quality criteria to establish loading capacities for various flow conditions. This builds on using flow duration curves, which use hydrologic data from stream gages to evaluate the cumulative frequency of historic flow data over a specified period. A duration curve relates flow values to the percent of time those values have been met or exceeded. A criterion concentration can then be converted into a distribution of allowable loads as a function of daily flow. Duration curve analysis identifies intervals, which can be used as a general indicator of hydrologic condition (e.g., wet versus dry and to what degree). For more information on using load duration curves, see Cleland (2002; 2003) and USEPA (2006b).

- **General Watershed Model.** For this document, general watershed models are assumed to be those that provide simulation capabilities and output on a non-daily basis, typically monthly or event-based. The models simulate basic watershed processes related to weather, erosion, and runoff and pollutant washoff, and they typically do not involve waterbody response or in-stream fate and transport. Examples of general watershed models include Generalized Watershed Loading Functions (GWLF) or Annualized Agricultural Nonpoint Source Pollution Model (AnnAGNPS).

- **Export Coefficients/Pollutant Budgets.** This category encompasses a number of approaches built on empirical relationships among watershed processes and pollutant loading as well as the use of literature values of typical watershed loading rates. Examples include using monthly load rates from various land uses to calculate allowable loading from an impaired watershed. Another example is using an empirical relationship that allows a user to calculate an allowable load depending on desirable conditions (e.g., target runoff/waterbody concentration or indicator levels).

- **Steady-State or Mass-Balance Analysis.** These approaches rely on the assumption of conservation of mass into a waterbody. The analysis might calculate loads entering a waterbody on the basis of literature values or observed data and calculate the resulting waterbody concentrations on the basis of estimated losses (e.g., settling, decay) and inputs. The approach relies on identifying the necessary loads entering a waterbody that will meet the desired waterbody target after the consideration of all inputs and losses. These approaches can be applied for a steady-state critical condition, in which case they might result in a daily load; in other instances they are based on longer time periods, such as average monthly loading rates.

For TMDL approaches using a dynamic model with daily output, load duration curves, continuous monitoring data, and in some cases, steady-state analysis, the daily load dataset is available as an output of the technique itself. As mentioned in the previous section, when a technical approach results in longer-term output, additional analysis is required. General watershed models and export coefficients are two techniques for which additional analysis is usually needed to create the necessary daily load dataset. In some instances, additional analysis might be required for steady-state or mass-balance calculations as well. The following section describes in more detail the options for developing a daily load dataset from various technical approaches with daily and non-daily output.

Developing Daily Datasets from Commonly Used TMDL Approaches

This section discusses the approaches and considerations for developing the dataset of allowable daily loads given the use of some commonly used TMDL approaches.

Daily Output Methodologies

- Detailed dynamic watershed models
- Load duration curves
- Continuous monitoring data
- Steady state/mass balance

Non-daily Output Methodologies

- General watershed models
- Export coefficients
- Mass balance calculations
- Steady state models

Dynamic Models

Dynamic models can be readily used to generate time series of daily loads for a TMDL allocation scenario. As discussed above, these models typically provide daily or subdaily output for flow and pollutant concentrations. Examples of dynamic watershed models frequently applied to TMDL development include the Soil and Water Assessment Tool (SWAT), HSPF and other similar dynamic models derived from the same algorithms such as WinHSPF and Loading Simulation Program in C++ (LSPC), and the Storm Water Management Model (SWMM). Despite the ability to output daily calculations, many TMDLs developed with such models present long-term LAs (e.g., monthly, annual). TMDL development with dynamic models generally involves designing the model to simulate a given time period that includes a variety of conditions. Depending on the characteristics of the system, a long simulation can be used that includes periods of drought and high flows or a shorter simulation can be run that includes a particularly critical condition (e.g., the 2-year low flow). The model is calibrated to observed data for the given model period and existing loading for the period is determined. Next, source loads are reduced until simulated loads meet WQS or representative targets. The daily loads for the model period can then be extracted from model output to be used in establishing the daily load expression.

Load Duration Model

Load duration curves (Cleland 2002, 2003; USEPA 2006b) are widely used to develop TMDLs, especially for pollutants where numeric water quality criteria are applicable. This approach involves calculating the allowable loadings over the range of flow conditions expected to occur in the impaired waterbody. This method generally presents loading data as a function of flow and can be used to extrapolate the daily load expression. The approach involves the following steps:

1. A flow duration curve for the stream is developed by generating a flow frequency table and plotting the data points. The data reflect a range of natural occurrences from extremely high flows to extremely low flows.
2. The flow duration curve is translated into a load duration (or TMDL) curve by multiplying each flow value by the WQS/target for a particular contaminant, then multiplying by a conversion factor. The resulting points are plotted to create a load duration curve.
3. Each water quality sample is converted to a load by multiplying the water quality sample concentration by the average daily flow on the day the sample was collected. Then, the individual loads are plotted as points on the TMDL graph and can be compared to the WQS/target, or load duration curve.
4. Points plotting above the curve represent deviations or exceedances from the WQS/target and the daily allowable load. Those plotting below the curve represent compliance with standards and the daily allowable load.

The load duration approach can be used to calculate a series of allowable daily loads, which is then used as the daily load dataset for identifying the daily load expression.

General Watershed Models

A variety of watershed and receiving water models capable of simulating different aspects of hydrologic and water quality processes exist; however, a relatively small number are commonly applied to TMDL development. This section focuses on those that are designed to predict average pollutant loads over time (annual, seasonal, monthly) as opposed to daily or shorter periods. The models simulate basic watershed processes related to weather, erosion, and runoff and pollutant washoff, and they typically do not involve waterbody response or in-stream fate and transport. In general, these models are continuous simulation, distributed models that produce monthly or annual loading estimates on the basis of daily weather inputs and runoff calculations. An example is the GWLF model and its improved Windows version, BasinSim 1.0 (available at http://www.vims.edu/bio/vimsida/bsabout.html).

Loads produced by such models can be translated to daily datasets in several ways. The simplest approach is simply to divide the load output by the number of days; however, this is likely to produce inappropriate results if the parameter of interest derives from washoff of nonpoint sources and is thus highly correlated to flow. As above, a better approach is to recognize the relationship between load and flow. To translate long-term TMDL loads developed by such models, an estimate or a simulation of daily flow data is needed. The flow can then be used to distribute the monthly load or seasonal load into variable daily loads. Data manipulation required to do this differs from model to model; however, the general process is the same:

- Start the analysis at the model basic time step (e.g., monthly).
- For each month, separate the approximately constant loads (point source, groundwater) from the surface washoff loads.
- Calculate an event mean concentration (EMC) for the surface washoff load by dividing the surface washoff load by the estimated surface runoff.
- Obtain daily, surface-runoff, flow data (1) from the model, if available, (2) baseflow separation on flow at nearby gages that represent similar watershed characteristics, (3) using established regression

equations from U.S. Geological Survey (USGS), or (4) using site-specific data. (For ways to develop flow data, see the discussion in the next section.)
- Multiply the daily surface flow volumes by the pollutant EMCs to derive the surface daily loads.
- Add the constant daily loads to the surface daily loads to derive the daily load dataset.

Export Coefficients

Export coefficients and export coefficient-based models such as PLOAD are applied in TMDL analyses to develop long-term estimates of pollutant yield on the basis of established loading rates by land use type. The methodology is often applied in watersheds where site-specific monitoring data are scarce but where good information exists regarding land use and practices.

Results of an export coefficient assessment differ from watershed model results in that the technique does not base results on calculations of flow. To obtain flow data necessary for establishing daily load expressions, more analysis is necessary. Even though flows are not inherently available as a product of the analysis technique, the translation process assumes that loading is related to runoff and distributes the available load according to daily flows. Using the loads calculated in the analysis and available flow data, a representative pollutant concentration can be calculated. The same techniques discussed under general watershed models can then be used to develop daily loads for the representative period. Sources of flow data are varied and can include modeled flows, nearby USGS gages, or estimations based on rainfall distribution patterns. In some areas, regression equations might have been developed for predicting flows in un-gaged streams.

Steady-State and Mass-Balance Models

Steady-state approaches rely on the assumption of conservation of mass into a waterbody. A typical TMDL analysis might calculate loads entering a waterbody using literature values or observed data, then calculate the resulting waterbody concentrations considering estimated losses (e.g., settling, decay) and inputs. The approach relies on identifying the necessary loads entering a waterbody that will meet the desired waterbody target after the consideration of all inputs and losses. These methodologies are generally applied for a single critical condition, such as during the 7Q10 low flow, to ensure criteria are met at all times. In other situations, mass balance calculations provide long-term TMDL loads by estimating watershed loading from back calculations of known waterbody concentrations and inflow volumes. Applying steady-state analyses to TMDL development is most appropriate in situations where streamflow and water quality are dominated by a relatively constant input, for example by a point source or sources. Mass-balance calculations are also frequently applied to lakes and impoundments.

Other scenarios in which steady-state/mass-balance models have been applied are in cases where monitoring data are lacking such that a more detailed watershed model is not justified and cannot be reasonably calibrated. When applied to TMDL development in this case, steady-state models represent a screening level of analysis pending development of more detailed monitoring data to support a more detailed TMDL analysis. Output of the steady-state analysis represents a reasonable maximum daily load expression for the critical conditions being evaluated and no further analysis or translation is necessary, if it is expressed in a per day basis.

In summary, a steady-state model is used to calculate the allowable loads from all represented sources, under a specific waterbody conditions (e.g., 7Q10 flow, impoundment design volume) given a desired water quality endpoint. Figure 8 provides an illustration of a mass-balance-type model showing a stream broken into model segments and point source inputs along the length. Results represent the allowable loads from point sources for the modeled condition (7Q10 flow). In some cases, the predicted input loads at critical conditions could be considered the maximum daily load for all conditions. In other cases, it might be preferable, if data are available, to extrapolate the allowable load at critical conditions to comparable loads at other flow regimes.

Streamflow	7Q10
OR0019223	2.1 MGD
OR0019001	.5 MGD
OR0018236	1.2 MGD

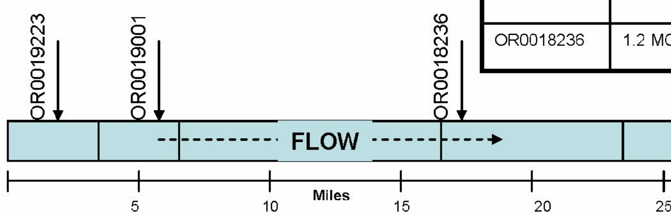

Figure 8. Example—Mass-balance model representation

Other mass-balance-type calculations include load estimates established for longer-term periods (e.g., monthly, annual). For example, a lake impaired by eutrophication might have a monthly average phosphorus concentration established as a target to support designated uses. To calculate the TMDL, the target concentration can simply be multiplied by the lake volume and an appropriate conversion factor, resulting in an allowable in-lake monthly load. A mass balance calculation could then be used to identify the allowable incoming watershed load, after subtracting out the losses (e.g., settling, uptake, outflow). When using a mass balance approach, the resulting allowable load will be calculated in the same units as the target; for example, monthly in the lake example. These in turn can be converted to constant daily loads or daily load series as a function of flow.

Options for Estimating Flows to Support Development of the Daily Load Dataset

In cases where daily loads are not an output of the TMDL analysis, daily flows are typically used to distribute the non-daily output into a series of daily loads, as discussed in previous sections. However, continuous or frequently measured daily flows are not always available. This section provides some options for developing flow data when data are not available for a waterbody. There could be a high degree of error associated with making these flow estimates (depending on the approach that is selected and the available data), and practitioners should consider this when developing the margin of safety (MOS) for the TMDL and recognize it in the final TMDL report.

Estimating Flows from Nearby USGS Gages

Obtaining flows from a nearby USGS gage is likely the most straightforward option for developing flows to be used in creating the daily load dataset. If no gage is in the TMDL watershed, one outside the watershed may serve as a surrogate. Be careful to locate a gage with a data record covering the same time period for which the TMDL analysis was performed and in near enough proximity that regional characteristics such as soil types and vegetative cover is similar. In addition, practitioners should make an effort to select a gaged watershed with land use characteristics similar to the TMDL watershed, having no significant flow restrictions or augmentations (e.g., impoundments,

When a Daily Dataset Cannot Be Developed with the Available Data

In certain circumstances, data limitations could be such that it is inappropriate or infeasible to derive flows and, therefore, daily loads through the options identified in this section. For example, there might be no nearby gages in watersheds similar to the target, rainfall data may be unreliable, not available, or the region could be arid.

In these cases, it might be most appropriate to establish a daily maximum load target on the basis of the long-term average using a statistic approach or assuming a particular critical condition. For more information, see Section 3.

diversions, withdrawals) that would skew results of the comparison. Daily flows for the gaged watershed can then be adjusted for the TMDL watershed on the basis of the ratio of the watershed areas. In many cases, it will be appropriate to use a baseflow separation program to evaluate the components of flow that are due to surface washoff.

Estimating Flows from Existing Models

If hydrologic modeling has been conducted in the watershed, modeled flows might be available. To be appropriate, the modeled flows should be representative of the period covered by the TMDL loading analysis, and they should be available on a daily time-step. While an option, this might not be a very likely one, and if data to support such a model existed for the watershed, chances are good that the TMDL would have been based on it rather than the coarser technique. Nevertheless, a hydrologic model of the watershed might be available to provide sufficient flow data for distributing the non-daily output into a series of allowable daily loads.

Estimating Flows Using Rainfall Distribution

Simplified modeling approaches (such as the Soil Conservation Service Curve Number approach) can be used to estimate runoff as a function of rainfall, soil type, and cover. Rather than running a continuous simulation, an option is to convert a statistical distribution of rainfall directly into a frequency distribution of flows.

Estimating Flows Using Regression Equations

For various areas around the country, regression equations might have been developed by water resource agencies to estimate flows for un-gaged streams. The USGS National Streamflow Statistics Program can provide flow percentiles for some areas of the country. These percentile flows can be used to construct a flow duration percentile curve. Currently the capability is available only for 11 states in the United States, allowing flow statistics to be computed for un-gaged watersheds. The stream statistics program uses regression analysis to relate streamflow statistics computed for a group of selected stream gaging stations (usually within a state) and basin characteristics measured for the stations. Basin characteristics measured for un-gaged sites are entered into the resulting equations to obtain estimates of the streamflow statistics. Alternatively, you could contact state or local agencies to see if any local regression equations are available for estimating flows from un-gaged watersheds.

Select Sources for Information on Regression Equations

ENSR. 2003. *Determining Streamflow Statistics for Ungaged Watersheds in Maine.* 04933-003-100. Prepared for New England Interstate Water Pollution Control Commission. May 2003.

Flynn, R.H. *Development of Regression Equations to Estimate Flow Durations and Low-Flow-Frequency Statistics in New Hampshire Streams.* U.S. Geological Survey Water-Resources Investigations Report 02-4298. U.S. Geological Survey, Reston, VA. <http://pubs.usgs.gov/wri/wri02-4298/wri02-4298.pdf>.

Ries, K.G., III, and P.J. Friesz. 2000. *Methods for estimating low-flow statistics for Massachusetts streams.* U.S. Geological Survey Water Resources Investigations Report 00-4135. U.S. Geological Survey, Reston, VA. <http://pubs.usgs.gov/wri/wri004135/ >.

Stuckey, M.H. 2006. *Low-flow, base-flow, and mean-flow regression equations for Pennsylvania streams*, U.S. Geological Survey Scientific Investigation Report 2006-5130. U.S. Geological Survey, Reston, VA.

USGS National Streamflow Statistics Program: http://water.usgs.gov/osw/streamstats/ssonline.html

3. Selecting the Daily Load Expression

This section provides guidance related to Step 3—Select Daily Load Expression. Once the daily dataset is created in Step 2, use it to identify an appropriate daily load expression to supplement the longer term TMDL allocations. This section provides information to support crafting the daily load expression, including discussing types of daily loads expressions as well as how to identify appropriate target values on the basis of system characteristics. In addition, various options for presenting the daily load expression in graphical and tabular form are included.

What Are the Goals of this Section?

- Present different options for expressing the daily load (static and variable)
- Provide guidance for selecting the appropriate option
- Provide guidance for selecting appropriate target values (e.g., load percentiles)
- Present example graphic and tabular representations of daily expressions

Types of Daily Load Expressions

Two basic options are available for presenting daily loads. First, a static expression—a single daily load number or set of numbers applicable to all conditions in the waterbody—may be presented. Second, a variable expression may be used in which the applicable daily load value is determined as a function of a particular characteristic that affects loading or waterbody response, such as flow or season. Of these, the most common options will be targets that vary by flow (flow variable) and those that vary by month or by season (temporally variable). Because TMDLs are unique in nature, there is no specific format for presenting static or variable daily loads and the options presented here do not preclude variable targets based on other characteristics.

Static Daily Load Expressions

A static daily load expression consists of a single number (e.g., daily maximum) or set of numbers (e.g., daily average and daily maximum) that represent the daily load value for all conditions. Such an expression is generally suitable for situations in which source inputs are relatively constant such as an effluent dominated stream in a small watershed. In addition, a static daily load expression may be developed for waterbodies where more complex loading and parameter interactions are involved as long as the expression addresses the variability of the daily loading expected to occur under the allowable loading scenario (the TMDL condition).

For example, in a watershed impaired by organic enrichment and oxygen depletion for which dynamic modeling results have determined a long-term load that satisfies water quality criteria, an approach would be to use statistical considerations to specify a limit on the daily load that is consistent with achieving the long-term TMDL load as determined by the model output.

Achieving the cumulative load over a given period of time is equivalent to achieving the average daily load over the same period of time. However, there will be natural variations in the individual loads while still maintaining the average, with some days exceeding the average and some well below it. Therefore, the question for the daily maximum load expression would be, given a certain average daily load, what is the maximum daily load consistent with attaining that average? The answer depends on the distribution of daily loads about the average. For example, suppose WQS will be attained if the pollutant load during the month of June does not exceed 30 kg. This is equivalent to an average load of 1 kg/d; however, the load on individual days will vary. The daily loads under the TMDL allocation scenario meet the average of 1 kg/d, but have a possible range from 0.1 to 10 kg/d (on the basis of predicted modeled values). Clearly, a daily load up to 10 kg/d is consistent with meeting standards, as long as the average daily load (and therefore, the cumulative monthly load) is met. Therefore, the maximum daily load expression could be set at 10 kg/d, as long as the TMDL allocations also specify that the cumulative load limit of 30 kg (or the equivalent daily average of 1 kg) is also met.

Using the Daily Load Dataset to Identify a Maximum Daily Load

The daily load dataset that is consistent with the TMDL serves as the starting point for identifying the static daily load expression. In the case where a long term daily load dataset is available, in which multiple years of data and a variety of environmental conditions are represented, it is preferable to select a maximum daily load as a percentile of the load distribution. A sufficiently long-term dataset allows for minimizing error associated with the fact that the daily load dataset might not exactly match a normal or lognormal distribution. For dynamic model output, the maximum daily load expression would be taken directly from the output scenario representing the TMDL.

Instead of selecting the maximum load value as the daily load, it is advisable to select a value that represents a high percentile (e.g., 95th or 99th), but not the maximum, of the distribution to protect against the presence of anomalous outliers. For example, selecting the 95th percentile implies a 5 percent probability that a daily load will exceed the specified value under the TMDL condition. Selecting higher percentile values as the maximum daily target is justified when there is high confidence in the accuracy of the dataset for extreme values. In cases where the analysis is based on a number of assumptions and there is a higher uncertainty in the analysis, it might be more appropriate to select a lower and, therefore, more conservative, maximum, providing an MOS. Whether the maximum daily load selected is based on the 75th or the 99th percentile load or some value in between, the TMDL developer should determine this on the basis of the site-specific issues and characteristics.

Using Statistical Analysis to Identify a Maximum Daily Load

In other cases, long periods of continuous simulation data will not be available—either because the analysis was developed without using a daily or subdaily dynamic model or because the period of prediction is too short to reliably estimate upper percentiles. EPA's *Technical Support Document for Water Quality-based Toxics Control* (USEPA 1991) describes a statistical approach to identifying a maximum daily load in such circumstances. The approach included in the Technical Support Document (TSD) is considered here for two cases—normally distributed daily loads and lognormally distributed daily loads. (Further details on the derivation of the approach as well as definition of parameters are in USEPA 1991.)

Which Number is the Right Number?

For a static expression, the maximum daily load value is set to represent the allowable upper limit of load values that are consistent with the long-term average required by the TMDL. This means selecting some appropriate maximum load from the daily load dataset (i.e., some percentile load value) that will account for high-flow events while not relying too heavily on potential outlier values. Some factors to consider when deciding which number (e.g., 90th, 95th, or 99th percentile) to set as the daily maximum load include the following:

- **Confidence in the Original Analysis Representing Actual Conditions**—A lower percentile is appropriate if there is concern that the model could over-predict loads on individual days. If the model calibration is well within the range of observed data, a higher number could be used.
- **Representativeness of Underlying Dataset**—TMDL analyses are highly dependent on the data on which they are built. For example, the data available for model calibration could skew the simulated conditions if the data do not cover a wide range of conditions. Fewer data translate into a calibration with more uncertainty; therefore, a lower value should be selected.
- **Type of Error Associated with Analysis**—Policy decisions regarding the balance of Type I errors (judging a daily load acceptable when it is actually not consistent with the longer-term average implied by the TMDL) and Type II errors (judging a daily load unacceptable when it is actually consistent with the TMDL).

In the case where the daily data are normally distributed about the mean, the maximum daily load expressed as the *p*th percentile of the distribution is calculated as

$$MDL = \mu + Z_p \sigma = \mu + Z_p \, {CV}/{\mu},$$

where MDL is the maximum daily limit, μ is the mean of the distribution (in this case, the average load to achieve WQS), σ is the standard deviation of the daily loads, *CV* is the coefficient of variation of the daily loads (standard deviation divided by the mean), and Z_p is the *p*th percentage point of the standard normal distribution. (Z-scores are published in basic statistical reference tables and are often included as a spreadsheet function [e.g., NORMSINV(y) in MS Excel]. For the 95th percentile, $Z_p = 1.645$, and for the 99th percentile, $Z_p = 2.326$.)

In the case where the daily data are lognormally distributed about the mean—as is often the case with loads that are dependent on flow magnitude—the MDL corresponding to a long-term average (LTA) calculated in the TSD relates the permit MDL to the desired LTA as

$$MDL = LTA \cdot \exp\left(Z_p \sigma_y - 0.5 \sigma_y^{\,2}\right),$$

where
Z_p = pth percentage point of the standard normal distribution, as above
CV = coefficient of variation of the untransformed data
$\sigma_y = \sqrt{\ln\left(CV^2 + 1\right)}$

As a result, the LTA multipliers for the MDL given in Table 5-2 of the TSD as a function of CV can be used to derive the MDL from the long-term average load that meets loading capacity where the lognormal assumption is appropriate. (Of course, this reasoning applies only when direct limitations on individual daily loads are not needed to achieve WQS.)

For example, suppose the loading capacity for the month of June is 60 kg, so the average daily load is 2 kg/d. Suppose further that these data are lognormally distributed, with a coefficient of variation of the untransformed data of 0.5 and that the 95th percentile value is to be selected as the daily load expression (Zp = 1.645). Then

$$\sigma_y = \sqrt{\ln\left(CV^2 + 1\right)} = 0.47238$$

and

$$MDL = 2\ kg/d \cdot exp\ (1.645 \cdot 0.47238 - 0.5 \cdot 0.223) = 2\ kg/d \cdot 1.945 = 3.89\ kg/d.$$

The TMDL would then contain a daily load expression (for June) of 3.89 kg/d as the maximum acceptable value consistent with achieving the monthly cumulative load target of 30 kg and the daily average of 2 kg/d. Actual attainment of the WQS depends on meeting the cumulative load target, which is equivalent to an average daily load of 2 kg/d; however, achieving that load is fully consistent with individual daily loads as high as 3.89 kg.

Again, using the approach from the TSD (USEPA 1991) to develop a maximum daily load is advised when the daily load dataset covers a limited period of time and there is a degree of uncertainty about the accuracy of predicted load values on the extreme ends of the distribution.

Variable Daily Load Expressions

An alternative to the static daily expression is the variable daily load. A variable daily load might be the preferable approach for waterbodies where loading rates change significantly because of the characteristics of different source inputs or waterbody conditions. A variable expression can also be used to inform the post-implementation monitoring process more readily than a static expression because monitoring data can be more easily compared to corresponding flow range or temporal targets.

Flow Variable

Developing a flow-variable target begins with load frequency analysis of the daily load dataset. Establishing a load duration curve of the allowable daily loads can represent the daily load expression. The curve represents a dynamic expression of the allowable daily load as a function of the measured flow for the respective day (Figure 9). Alternatively, separate daily loads can be identified for select flow conditions. For example, EPA's *An Approach for Using Load Duration Curves in the Development of TMDLs* (USEPA 2006b) illustrates grouping flow intervals into five zones representing high flows (0–10 percent), moist conditions (10–40 percent), mid-range flows (40–60 percent), dry conditions (60–90 percent), and low flows (90–100 percent). For each of these flow categories, a daily maximum load and a daily average load can be identified as the daily load expression for the respective TMDL. For example, Figure 10 illustrates an example TMDL setting the 95th percentile load for each flow category as the daily maximum load along with the 50th percentile load as the allowable daily median load.

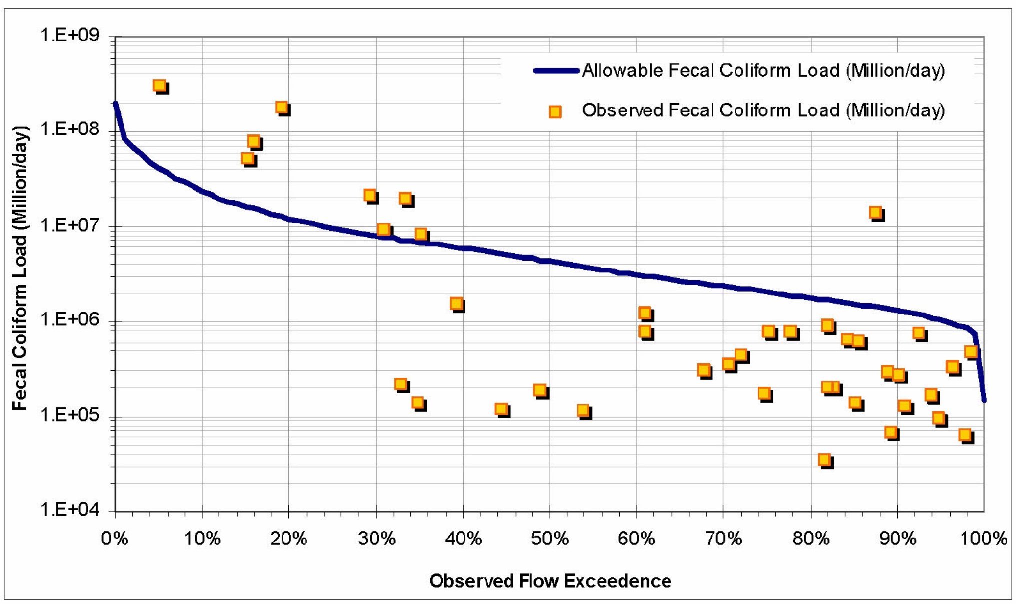

Figure 9. Load duration curve representing dynamic allowable daily fecal coliform loads based on observed flow.

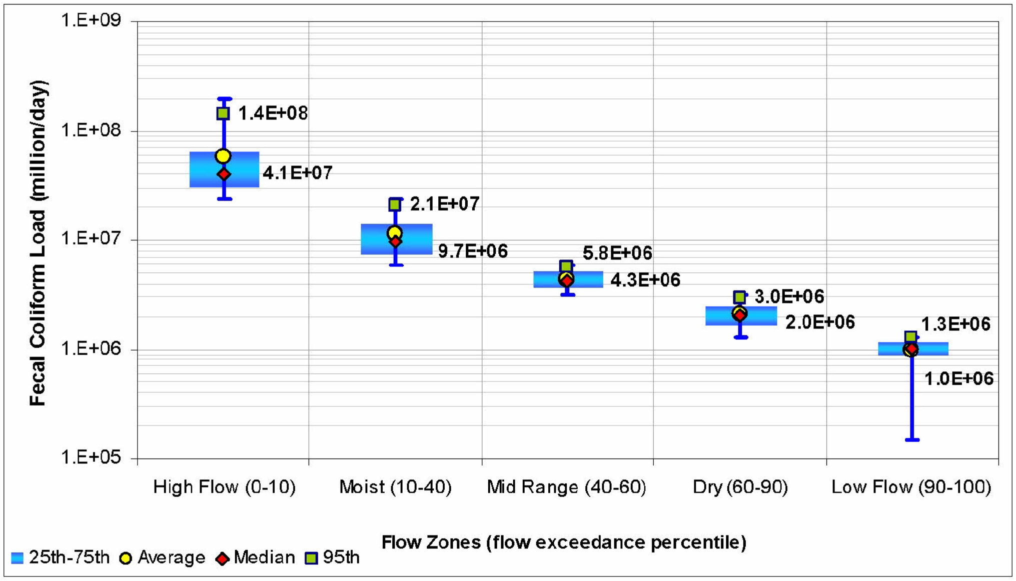

Figure 10. Daily load expressions by flow category.

Temporally Variable

Temporally variable targets might be desirable when source inputs vary significantly by month or by season. For this method, the daily load time series is segregated into suitable time periods, load values for each period are ranked according to frequency, and appropriate targets are identified (e.g., mean and 95th percentile). Figure 11 presents a graphical example of a seasonally variable daily load expression with a daily maximum load set at the 95th percentile load and a corresponding daily average load.

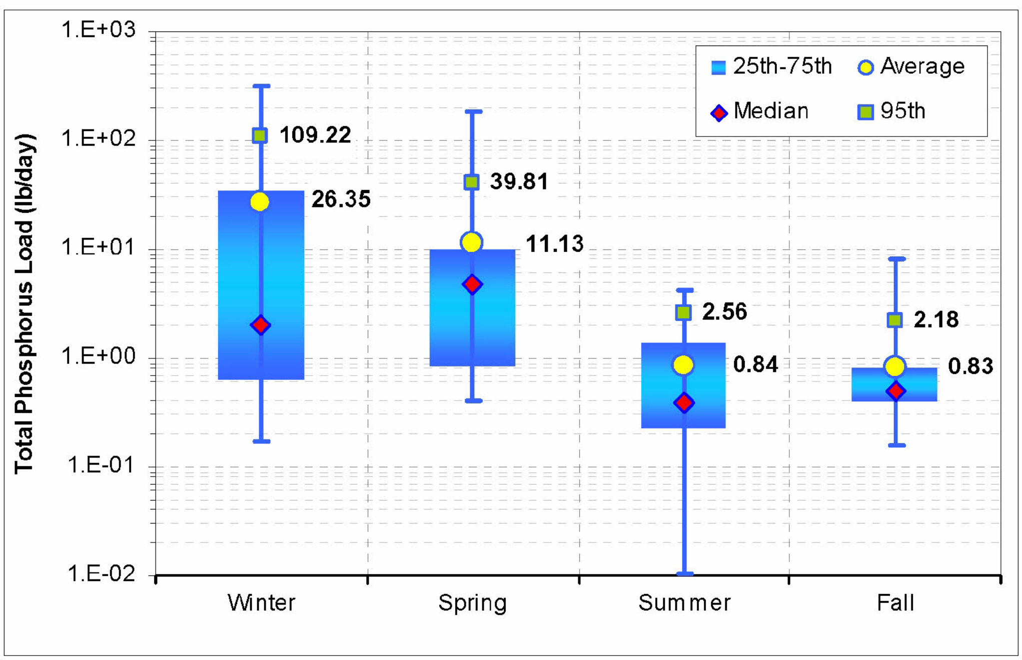

Figure 11. Example of a seasonally variable daily load expression.

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Considerations for Selecting the Appropriate Daily Load Expression

Selecting the appropriate type of daily load expression (static or variable) and the associated target value is driven by the characteristics of the waterbody for which the TMDL was calculated as well as characteristics of the analysis used for developing the non-daily TMDL allocations. Factors such as data availability, assumptions made during the TMDL analysis, and time period addressed by the non-daily allocations can all affect the selection of the daily expression. When making the decision, the practitioner should take into account management implications, critical loading conditions, and pollutant sources and behavior while maintaining consistency with assumptions from the non-daily TMDL analysis. While TMDLs differ from one to the next, there are some general tendencies that can be used to guide selection of the appropriate daily load expression. This section outlines basic issues to consider in crafting the expression on the basis of the *analysis categories* of pollutant source type, waterbody type, and critical conditions.

Maintain Consistency with the Original Approach

In developing the daily load dataset, you should take care to not apply different assumptions from those used in the original TMDL analysis. For example, if a PLOAD analysis predicts annual loads using precipitation data from 1990 to 1996, flow data obtained to develop a daily load dataset should be from the same period.

Another example is presented by a TMDL with an annual LA based on a series of modeled daily loads representing a loading scenario that meets WQS. You should develop the daily load expression from the range of modeled daily loads, rather than using a separate analysis. For example, developing a daily target by multiplying observed or modeled flow by the numeric criteria to develop a load duration curve is inconsistent with the loads used to calculate the original allocations.

Factors associated with specific parameters of concern can provide some direction as to the appropriate daily load option to use; however, other considerations such as critical conditions and pollutant source types will be more indicative of the approach to use. The tables below provide a general rating (high, medium, low) of the appropriateness of the various daily load options compared to several critical TMDL considerations such as pollutant source type, critical conditions, pollutant behavior, and waterbody type. Because of the complexities of TMDL analysis, multiple critical considerations will affect selection of the daily load option and target selection. The matrixes are not absolute; they are presented as a broad guide to the types of expressions that will generally be appropriate for the specific TMDL analysis. Where possible, examples of typical situations in which the option might be considered are listed.

Pollutant Source Types and Critical Conditions

The type of pollutant sources involved in the TMDL can affect the expression of the daily load in a number of ways. For example, pollutant source type can be a good indicator of critical conditions. Point source-dominated waterbodies tend to experience water quality problems due to discharges overwhelming receiving streams. In a point source-dominated, impaired segment, critical conditions generally occur during low flows when less stream flow is available to dilute the discharge. Target selection will generally focus on ensuring that WQS are attained during critical low flows. Static, daily load expressions could be reasonable in some situations either by using the TSD approach to identify maximum daily loads associated with a long-term average load or by applying steady-state model results directly as the maximum daily load. Nutrient and bacteria contributions from failing onsite sewage treatment systems, in general considered a nonpoint source of pollution, behave like point sources in this regard.

Legend

High—usually the most appropriate option for the factor under consideration given relatively straightforward applications.

Medium—often an appropriate option for the factor under consideration and may be prioritized over options rated *High* when particularly unique situations are present or other considerations override the current factor in importance.

Low—sometimes an appropriate option for the factor under consideration, especially if analysis factors present unique situations such that the *High* or *Medium* options are less appropriate.

Nonpoint source-dominated streams tend to experience impaired conditions as a result of rainfall events and associated runoff. As a result, flow-variable daily load expressions might be a good option to use in crafting the daily target. Critical conditions are often associated with high flows; however, this is not always the case because some nonpoint sources (e.g., septic systems) can contribute to impaired conditions during low flows.

Finally, in waterbodies with a mix of both point and nonpoint sources, there could be multiple critical conditions or none apparent at all. For example, in a watershed where metals loading is attributed to mining activity as well as legacy land use issues, continually flowing mine discharges can contribute to the impairment during low flows, while runoff from abandoned mine lands contributes during rainfall events. A variable daily load expression might be most appropriate for mixed source watersheds; although practitioners might consider crafting a static expression as well. A variable expression could also be a good option for states that need to develop *batches* of TMDLs for multiple watersheds where some watersheds could be dominated by point sources and others by nonpoint sources, yet the TMDL submittals, including the LAs, need to be consistent in format. Table 2 and Table 3 provide a general ranking of the appropriateness of using the various daily load options in relation to pollutant source type and critical condition considerations.

Table 2. Target option and pollutant source type considerations

Pollutant source types	Daily load expression option		
	Static	**Flow range variable**	**Temporally variable**
Point source-dominated ▪ Water quality problems often related to discharge that overwhelms receiving stream's dilution capacity ▪ Critical conditions generally occur during low flows	**High**—Could be appropriate for steady state analysis TMDLs or when dynamic modeling output is used in conjunction with the TSD approach for identifying the maximum daily load (e.g., nutrient loads from a wastewater treatment plant)	**Medium**—Consider when discharges are related to precipitation and critical conditions occur at a particular flow range (e.g., municipal separate storm sewer systems [MS4s], stormwater, combined sewer overflows [CSOs], surface mines)	**Low**—Might be appropriate if discharges are seasonal in nature (e.g., power plants, wastewater treatment plants [WWTPs] in a summer vacation area where population increases)
Nonpoint source-dominated ▪ Water quality problems often related to precipitation/runoff events ▪ Critical conditions generally occur during high flows	**Medium**—Could be appropriate to apply TSD approach to long-term average load to develop corresponding maximum daily value. Consider if parameters are relatively constant but from nonpoint sources (e.g., septics, abandoned mine land seeps, sediment oxygen demand, sediment as in-stream source of metals)	**High**—Might be appropriate when problem conditions occur with varying intensity across different flow ranges (e.g., streambank erosion)	**Medium**—Could be appropriate when sources are seasonal in nature (e.g., agricultural, summer season campground package plants)
Mixed point source and nonpoint source ▪ Water quality problems associated with precipitation/runoff events (nonpoint source) and dry-weather point source discharges ▪ Different sources impact stream at different flow ranges	**Medium**—Could be appropriate to apply TSD approach to long-term average load to develop corresponding maximum daily value	**High**—Could be appropriate for problem conditions that occur with varying intensity across different flow ranges	**Medium**—Could be appropriate when sources are seasonal in nature (e.g., agricultural, summer season campground package plants)

Table 3. Target option and critical condition considerations

Critical condition	Daily load expression option: Static	Flow range variable	Temporally variable
Low flow	**High**—Consider when steady-state analysis was used for non-daily TMDL; point source dominated with little nonpoint source influence; critical conditions occur at multiple flow ranges	**Low**	**Medium**—Consider when problem conditions occur seasonally (e.g., nuisance algal growth in-stream due to summer low flows, slow flow rate, lack of shading)
High flow	**Low**	**High**—Consider when critical conditions are associated with precipitation/runoff events and sources include multiple source types	**Medium**—Consider when critical conditions are associated with precipitation/runoff events and occur seasonally
Seasonal	**Low**	**Low**	**High**—Consider when critical conditions are driven by seasonal factors (e.g., seasonal water quality criteria)

Source Behavior

Source behavior is another factor in selecting and applying the TMDL analysis approach, and therefore should be a consideration when selecting how to express the daily load. Major sources having seasonal impacts to a receiving water include certain land uses and activities including agricultural lands (e.g., fertilizer application to crops, grazing, tilling); forest areas (e.g., managed areas that may be burned or cleared); and urban areas (e.g., salting for deicing). For clearly seasonal pollutant sources, a temporally variable daily load is suitable. Constant sources might fit well with a static expression, while those that are precipitation driven (e.g., MS4s, CSOs, concentrated animal feeding operations [CAFOs]) might be more appropriate for a flow-variable target. In addition, when selecting the target option, practitioners should consider assumptions made during the TMDL analysis with respect to source behavior. If the analysis assumed a constant delivery rate of pollutant, a static daily load could be selected. For example, atmospheric deposition rates of parameters such as nutrients, mercury, and polychlorinated biphenyls (PCBs) differ for wet and dry conditions; however, assumptions could be made during the TMDL development process that certain pollutants are delivered on a more or less constant basis. Table 4 reviews source behavior considerations in relation to selecting the daily load expression.

Table 4. Target option and source behavior considerations

Source behavior	Daily load expression option		
	Static	**Flow range variable**	**Temporally variable**
Seasonal (e.g., agricultural nonpoint loading)	**Low**	**Medium**—Might be appropriate if seasonal source is also associated with specific flow regimes	**High**—Could be appropriate when seasonal sources dominate the waterbody response
Constant (e.g., atmospheric mercury)	**High**—May be appropriate to consider when source is fairly constant in nature or when the TMDL approach assumes a constant loading rate	**Medium**—Might be appropriate if impact of constant source is more critical during certain flow regimes (e.g., low flows) than others	**Low**
Precipitation driven	**Medium**—Might be appropriate to apply the TSD approach to develop single maximum associated with long-term average derived by dynamic or general watershed model	**High**—Might be appropriate when major sources are precipitation driven	**Medium**—Consider using if seasonal considerations are significant

Waterbody Type

Waterbody type affects selection of the daily load target less critically than the considerations discussed previously. However, some waterbody specific factors can affect daily load target selection. For example, in tidal areas, the flow-variable approach might not be readily applicable because flow in the waterbody cannot be readily measured nor is it necessarily an accurate indicator of available dilution. However, a flow-variable approach would still be applicable if the allowable loading is driven primarily by the load contained in free-flowing streams entering the waterbody. For lakes and impoundments, as well as free-flowing streams, selection of the daily load will be determined more by other factors such as pollutant source and critical condition than by the waterbody type itself. Table 5 discusses factors to consider related to waterbody type.

Table 5. Target options and waterbody considerations

Waterbody type	Daily load expression option		
	Static	**Flow range variable**	**Temporally variable**
Lake/Impoundment	**Medium**—Consider when major sources are point sources or with dynamic model output and the TSD approach	**High**—Consider when loads are driven by surface washoff in the watershed	**Medium**—Consider for situations where long-term and seasonal control of nutrients/sediment is important for meeting lake targets
Free-flowing river/stream	**Medium**—Consider for point sources; dynamic model output/TSD	**High**—Consider when loads are driven by surface washoff in the watershed.	**Medium**—Consider when major sources are seasonal in nature or if critical conditions occur seasonally
Tidal/estuarine	**Medium**	**Medium**—Consider when loads are driven by surface washoff in the watershed	**High**—Consider when major sources are seasonal in nature or if critical conditions occur seasonally

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Appendix A: Example Applications for Identifying Daily Load Expressions

This appendix presents example applications to identify daily load expressions for TMDLs for which long-term allocations were developed. Multiple scenarios are illustrated, covering a variety of TMDL technical approaches, pollutant source types, and parameters of concern as well as several different daily load expression options. Table 6 summarizes the characteristics of each example. Note that with the exception of the Anacostia River total suspended solids (TSS) TMDL example, all examples are hypothetical cases developed to highlight critical aspects of the conversion process. An effort was made to present examples representative of relatively typical TMDLs with respect to technical approaches, parameters of concern, critical analysis considerations, and pollutant source types. As with all TMDLs, unique aspects of a particular analysis should be considered when converting long-term loads to daily loads. In addition, for each example, conversion of the long-term load to a daily load is illustrated for the overall loading capacity (sum of WLAs and LAs) and is not broken down into source categories. For cases in which it is desirable to identify daily load expressions by source category, it is assumed that the same steps can be applied to the source-specific loads (see the Anacostia example for an alternative approach).

Table 6. Summary of examples of identifying daily load expressions for Non-daily TMDLs

Example	Parameter	Critical condition/source behavior	TMDL method	Daily load option
1. Bird Creek	Nutrient	▪ Source inputs vary both by time of year and by precipitation and flow	General Watershed Model (GWLF)—Monthly Output	Monthly Variable
2. Red River	Metals	▪ Little apparent loading relationship to flow ▪ Sources include legacy land use (abandoned mine drainage) and active, precipitation-driven sources (e.g., urban runoff) and point sources	Dynamic Model (LSPC)—Daily Output	Static
3. Royal Lake	Nutrients	▪ Lake conditions and source impacts are seasonal ▪ Sources are both nonpoint and point	General Watershed Model (GWLF)—Monthly Output	Seasonally Variable
4. Carter Creek	Bacteria	▪ Critical conditions are dependent on flow with varying sources dominated different flow conditions	Load Duration	Flow Variable
5. Muddy River	TSS	▪ Dominated by nonpoint sources ▪ Chronic loading is concern	Dynamic Model (SWAT)—Daily Output	Flow Variable
6. Pine Lake	Nutrients	▪ Limited water quality data ▪ Sources include both nonpoint and point sources	Empirical—Annual Output	Static
7. Anacostia River	TSS	▪ Major sources are precipitation driven ▪ Critical conditions are high flow	Dynamic Model (HSPF)—Daily Output	Static and Flow Variable*

*depending on source

Example 1: Bird Creek Nutrient TMDL

Problem Definition

Bird Creek was identified as impaired due to nutrients because of concerns over impacts on biological communities and excessive nutrient loading to a downstream lake. The watershed is primarily agricultural, including extensive cropland and a number of livestock operations.

TMDL Technical

The TMDL was developed for phosphorus using GWLF to estimate watershed loads. Because no numeric water quality criteria are available for nutrients, a target loading rate was developed using a reference watershed—a watershed similar in characteristics (e.g., soils, elevation, topography) to the impaired watershed and that supports its designated uses was identified as a *reference* watershed. GWLF was applied to the reference watershed to identify an acceptable loading rate (mass/area/time), and the loading rate was applied to the impaired watershed area to establish a target annual phosphorus load.

The model was then run for a variety of management scenarios to identify allocation and load reduction scenarios that met the target load. Load reductions were focused on controllable sources (e.g., agricultural uses) during times of highest loading and greatest impact (e.g., spring and summer).

TMDL Allocation

TMDL allocations were expressed on a monthly basis to account for the temporal variations in loading and resulting in-stream concentrations due to weather variations as well as source activity. Highest flows occur during late winter and spring resulting from the combination of rain-on-snow events, the melting of any remaining snow accumulated during preceding winter months, and spring rain showers. Low flows occur during summer months because of infrequent precipitation. Therefore, weather and flow conditions affect the seasonal variability in loading due to precipitation-driven loading from cropland and smaller urban areas. In addition, source loading varies temporally due to source activity, particularly summer and early fall grazing of livestock, as well as the increased activities for cropland use during spring and summer. As shown in Figure 12, average monthly flow and average monthly phosphorus concentration do not follow the same pattern throughout the year. During winter and spring, flow and concentration follow a similar pattern because in-stream phosphorus is primarily dominated by runoff carrying phosphorus from cropland and developed areas. During the late summer and early fall, in-stream conditions are also affected by sources that are not controlled by precipitation and runoff events, such as grazing livestock with access to the streams and nearby areas.

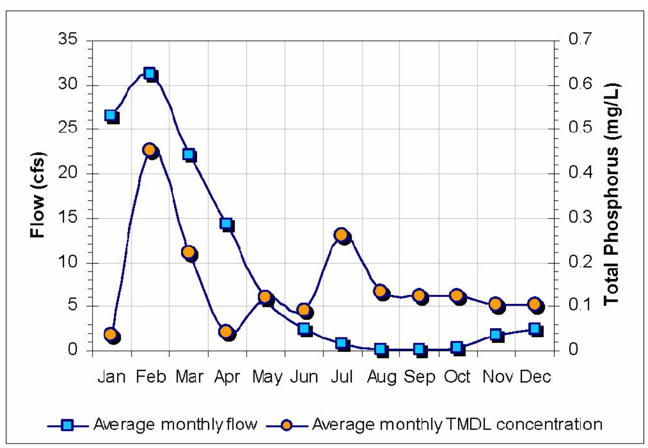

Figure 12. Average monthly flow and concentration in Bird Creek.

Supplementary

The GWLF model provides monthly output including flow volume and nutrient load. In addition to the model output, continuous daily flow data are available for the watershed from a USGS gage. The flow from this gage was used in the model calibration, and therefore the model appropriately represents the observed flow magnitudes and patterns.

Daily Load Dataset

GWLF model output was used with available continuous observed flows to develop the daily load dataset for identifying the daily load expression. Because phosphorus is predominantly loaded by surface pathways and major point sources are not present, it is not necessary to separately account for non-flow-related components. For each month, modeled phosphorus load and flow were used to calculate an average monthly phosphorus concentration. (Monthly concentrations are shown in Figure 12.) For example, for February the average flow was 18.27 ft^3/s, and the average monthly phosphorus load under TMDL conditions was 567.67 kg/month. Therefore, the average phosphorus concentration for February is as follows:

$$\frac{567.67\,\dfrac{kg}{month}}{18.27\,\dfrac{ft^3}{s}} \times \frac{month}{28\ days} \times \frac{day}{86{,}400\ s} \times 0.0353\,\frac{ft^3}{L} \times 1{,}000{,}000\,\frac{mg}{kg} = 0.45\,\frac{m}{L}$$

Daily flows (from gage data) were multiplied by the average phosphorus concentration for the respective month (and a conversion factor) to calculate a series of daily phosphorus loads, as shown in Figure 13.

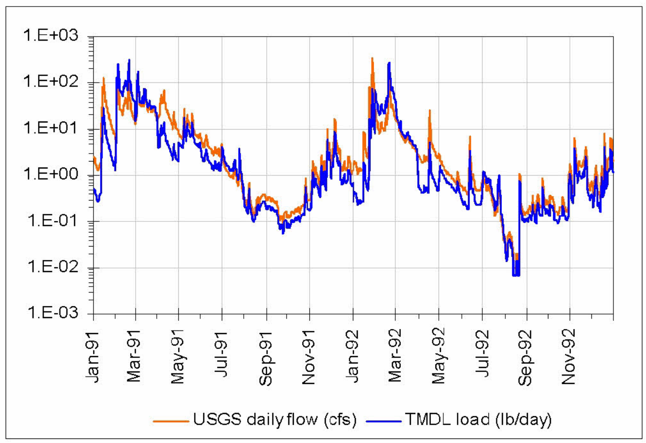

Figure 13. Estimated daily phosphorus loads.

Crafting the Appropriate Daily Load Expression

The factors and key issues considered in identifying the appropriate daily load expression include the following:

- *Non-daily Allocation Expression*—allocations were expressed on a monthly basis.
- *Source Behavior*—Sources are primarily nonpoint sources with a mix of precipitation-driven sources (e.g., cropland runoff) and sources with direct input to the stream (e.g., livestock grazing near receiving streams).
- *Flow Variation*—In-stream conditions do vary with flow because of weather and resulting flow patterns. However, source activities that are not dependent on flow conditions also affect the in-stream conditions.
- *Temporal Variation*—In-stream conditions vary widely among months and seasons. Not only are in-stream conditions influenced by temporal patterns in weather and the resulting runoff patterns, but also by source activity that varies by month and season (e.g., grazing schedules/locations, crop harvesting)
- *Follow-up Monitoring*—A year-long, intensive monitoring study is scheduled for the watershed within the next 5 years. The monitoring will include weekly sampling, reflecting a wide variety of conditions. During routine monitoring, the stream is sampled quarterly.

Daily Load Expression

The daily load expression for Bird Creek was established on a monthly basis to be consistent with the overall monthly allocations and includes a daily maximum (based on the 95th percentile load occurring during that month) and a daily average for each month, as shown in Figure 14 and Table 7. Expressions were established as monthly-variable to account for the variation in in-stream conditions resulting from both environmental conditions (e.g., weather, flow) as well as source behavior.

Monthly values will also provide greater insight into tracking progress during post-TMDL monitoring. Because an intensive monitoring study will provide multiple data points within each month as well as across months, the monthly expressions will provide a more accurate target to which data can be compared, rather than using a single value that is averaged over the entire year and does not represent the widely fluctuating conditions across months. Including both an average and a maximum daily load also provides more confidence and flexibility in tracking the post-TMDL water quality. Comparing data only to the maximum might provide biased results if sampling captures an unusually high event that results in localized peaks in phosphorus but does not affect longer-term conditions. Tracking against the average will provide a better understanding the long-term conditions.

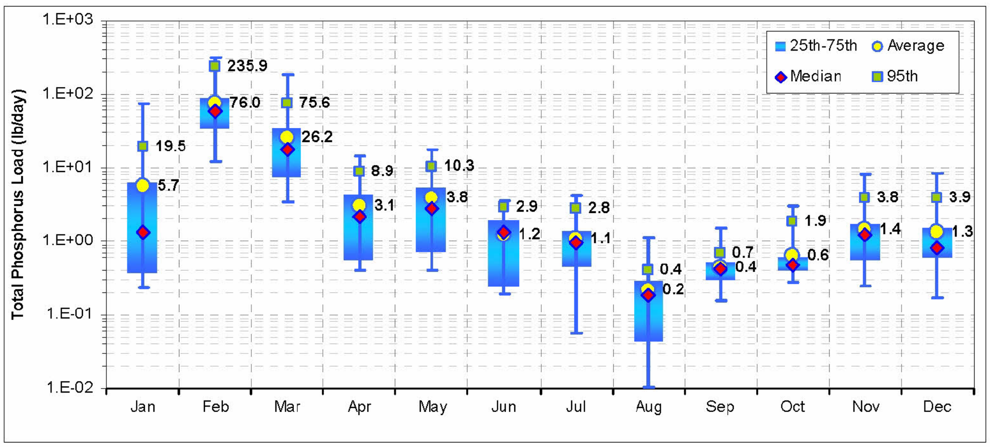

Figure 14. Daily maximum and average allowable total phosphorus loads by month.

Table 7. Daily maximum and average allowable total phosphorus loads by month

Month	Daily load targets: Daily average (lb/day)	Daily load targets: Daily maximum (lb/day)
Jan	5.7	19.5
Feb	76.0	235.9
Mar	26.2	75.6
Apr	3.1	8.9
May	3.8	10.3
Jun	1.2	2.9
Jul	1.1	2.8
Aug	0.2	0.4
Sep	0.4	0.7
Oct	0.6	1.9
Nov	1.4	3.8
Dec	1.3	3.9

Example 2: Red River Aluminum TMDL

Problem Definition

Red River was listed as impaired by a number of metals, including aluminum. The observed impairments are primarily due to recent and historical mining activities but are also influenced by urban runoff and industrial point sources.

TMDL Technical Approach

The TMDL was developed for aluminum using a dynamic watershed model, HSPF, to link watershed sources to in-stream response and identify the loading capacity to meet applicable water quality criterion (acute and chronic). The model was calibrated to existing conditions and then run for a variety of load reduction scenarios to identify allocations that met the criteria in all impaired segments.

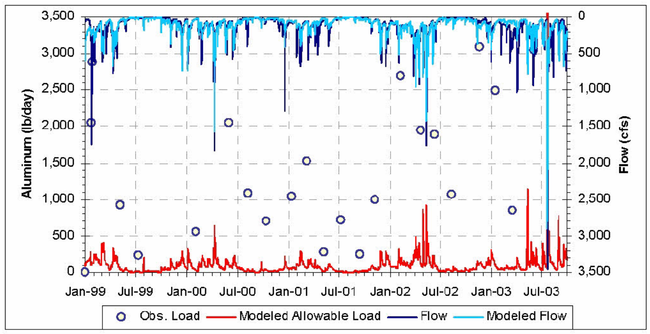

Figure 15. Modeled aluminum daily loads under TMDL conditions along with observed loads and modeled and observed daily flow.

TMDL Allocation Expression

TMDL allocations were expressed as annual loads based on an average annual load over the 5-year simulation period, representing a variety of climatic and source loading conditions.

Supplementary Data

Because the TMDL analysis used a dynamic model, it produces a time series of allowable daily loads. Supplementary data are not necessary to develop the daily load dataset for identifying the daily load expression.

Daily Load Dataset

The modeling analysis provides daily output of simulated loads, providing the daily load dataset. Alternatively, the daily load dataset could be developed using the observed flow record and multiplying it by the allowable criterion (much like a load duration analysis). However, because the TMDL allocations are based on the model output, it is most appropriate to again use the modeled output for identifying the daily load expression.

Crafting the Appropriate Daily Load Expression

The factors and key issues considered in identifying the appropriate daily load expression include the following:

- *Non-daily Allocation Expression*—allocations were expressed on an annual basis.
- *Source Behavior*—Sources include precipitation-driven nonpoint sources (e.g., urban runoff), discharges from active mines, and seeps/discharges from abandoned mine lands. Industrial discharges also impact the river.
- *Flow Variation*—In-stream conditions do vary with flow because of weather and resulting flow patterns. However, flow is not the only factor affecting loading to the river. There are a number of significant sources in the watershed that are not dependent on rainfall and resulting runoff and can impact the stream during all flow conditions (e.g., abandoned mine lands).
- *Temporal Variation*—While in-stream flow conditions vary among months and seasons and follow typical patterns from year to year, the pollutant loading and in-stream response does not exhibit an identifiable temporal pattern. This is likely due to the mix of sources contributing aluminum loading to the river and impacting the in-stream conditions.

Daily Load Expression

The river experiences critical conditions during low- and mid-range flow periods when inputs from abandoned mine lands impact in-stream concentrations and also during high flows when precipitation-driven runoff and discharges carry pollutant loads from urban areas and mine sites. There is also no defined pattern of variation among months or seasons. Therefore, daily load expressions were not based on flow conditions or for varying time periods. Instead, a static target was established on the basis of the long-term simulation data from the watershed model. Using the range of allowable daily loads, a daily maximum and a daily average were identified. The daily maximum target based on the 95th percentile and the daily average are presented in Figure 16 along with the range of allowable loads simulated by the model.

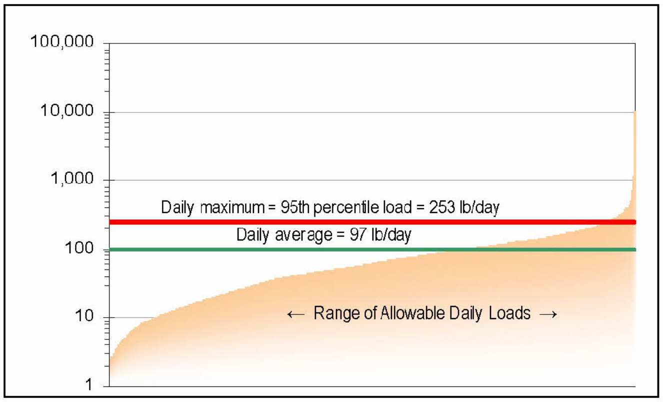

Figure 16. Daily maximum and average allowable load along with the range of allowable loads simulated under TMDL conditions.

Example 3: Royal Lake Nutrient TMDL

Problem Definition

Royal Lake was listed as impaired by nutrients and nuisance algal growth. The lake drains a mix of land uses, primarily high- and low-density residential with some isolated areas of concentrated animal operations. The lake experiences increased algal growth and resulting decreased dissolved oxygen in summer months—during times of warmer temperatures, more sunlight, and increased nutrient loads.

TMDL Technical Approach

The TMDL was developed for phosphorus using GWLF (through BasinSim) to estimate watershed loads and BATHTUB to simulate in-lake response. (Figure 17 presents the BATHTUB calibration for total phosphorus and chlorophyll *a* for a representative growing season.) The TMDL was established to meet a chlorophyll *a* target concentration, representing an acceptable level of algal growth based on literature values and historical data. The chlorophyll *a* target is expressed as a growing season average of 20 µg/L.

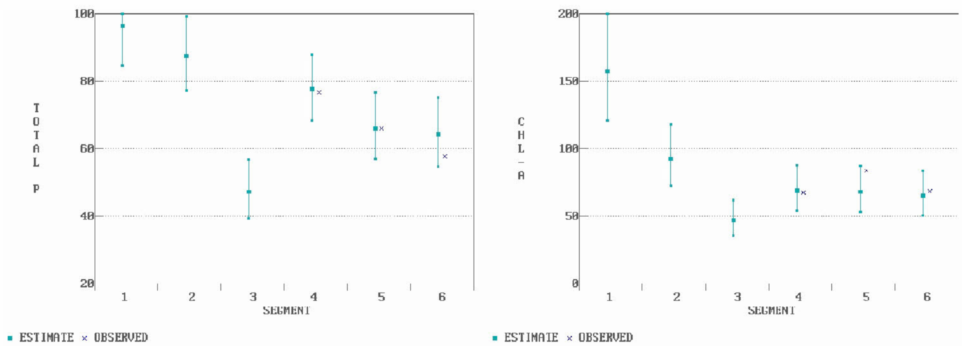

Figure 17. Example BATHTUB calibration for representative growing season.

The watershed and lake models were applied for a variety of load reduction scenarios to identify allocations to meet the target in-lake conditions.

TMDL Allocation Expression

TMDL allocations were expressed on a seasonal basis to meet the established water quality target representing a growing-season (i.e., summer) chlorophyll *a* concentration. Watershed loading also experiences seasonal variation due to seasonal patterns in precipitation and runoff, further supporting the use of seasonal allocations. Allocations were established by land use and subwatershed as well as for several point sources in the watershed (e.g., campgrounds, WWTPs).

Supplementary Data

As opposed to using the original version of GWLF, which calculates the water balance on a daily basis but provides only monthly output, the BasinSim interface allows the user to obtain the calculated daily flows, concentrations and loads. Those daily values can provide the necessary information to develop a time series of daily loads for identifying the daily load expression to accompany the seasonal allocations.

Daily Load Dataset

Estimated daily total phosphorus loads were provided by the model for the 5-year simulation period.

Crafting the Appropriate Daily Load Expression

The factors and key issues considered in identifying the appropriate daily load expression include the following:

- *Non-daily Allocation Expression*—allocations were expressed on a seasonal basis to be consistent with the established chlorophyll *a* target of a growing season average.
- *Impairment Conditions*—Nutrient-related impairments occur in the lake primarily during summer months when algal productivity is the highest. However, source loading throughout the year contributes to the nutrients available in the lake to support algal growth.
- *Source Behavior*—Because nonpoint sources are primarily precipitation driven, nonpoint loading is dependant on prevailing weather and resulting flow patterns. Precipitation and resulting runoff and tributary inflow to the lake exhibit strong seasonal variation, with the highest flows during winter and spring and the lowest flows during summer. Because point

sources discharge year-round, their relative impact is also seasonal, depending on how much water is available in watershed streams for dilution. Because summer experiences the lowest flows, point source impacts are the strongest during those months.

- *Temporal Variation*—Both in-lake conditions and source loading vary temporally. In-lake conditions vary most notably by season, with minimal variation among months within a season.

Daily Load Expression

The daily load expression for Royal Lake was established on a seasonal basis to be consistent with the TMDL allocations and includes a daily maximum and a daily average for each season, as shown in Figure 18. Seasonally variable daily load targets also capture the variations in both in-lake conditions and source loading and impacts. The daily maximum for each season is equivalent to the 99th percentile load in the series of allowable daily loads occurring during that season. The 99th percentile was chosen because of the relatively long simulation period, the confidence that the higher predicted loads were not outliers, and the extreme range of the simulated loads.

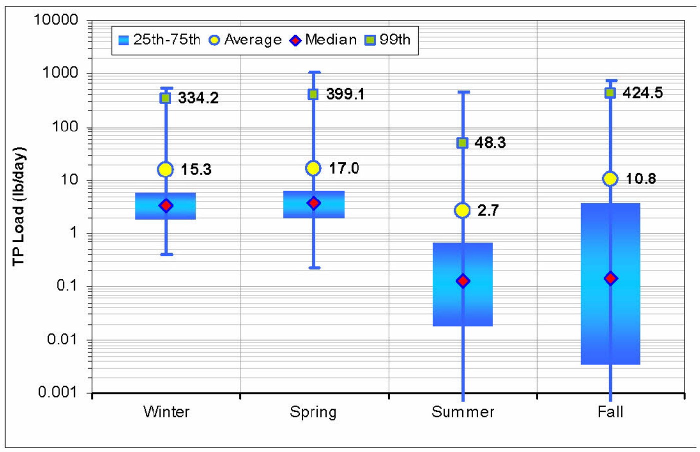

Figure 18. Daily maximum and average allowable loads by season.

AR0022570

Example 4: Carter Creek Bacteria TMDL

Problem Definition

Carter Creek was listed as impaired by bacteria with expected sources including commercial, residential, and agricultural runoff as well as failing septic systems.

TMDL Technical Approach

The TMDL was developed using a load duration approach. Using a continuous flow record, a flow duration curve was developed on the basis of the flow percentile, or the percent of time the respective flow value has been met or exceeded. The flow duration curve was then converted to a load duration curve by multiplying the individual daily flows by the bacteria target, equivalent to the not-to-exceed water quality criterion for fecal coliform of 400 counts/100 mL. Figure 19 presents the load duration analysis, including observed loads calculated on the basis of observed bacteria data and corresponding daily flows.

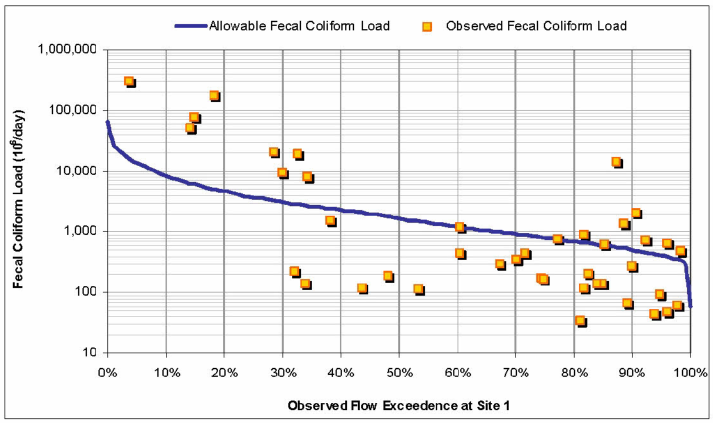

Figure 19. Load duration analysis for fecal coliform in Carter Creek.

TMDL Allocation Expression

TMDL allocations were expressed for various flow regimes to represent times of varying source loading and in-stream conditions. For example, precipitation driven runoff from residential areas and agricultural areas are expected to be dominant sources of bacteria during wet-weather conditions. In addition, the stream experiences elevated bacteria levels during low flows, likely due to failing septic systems that deliver bacteria loads through subsurface flows, influencing in-stream conditions during baseflow. The following flow categories were used for establishing allocations:

- *High-flow zone:* flows in the 0 to 10 percentile range, related to flood flows
- *Moist zone:* flows in the 10 to 40 percentile range, related to wet-weather conditions
- *Mid-range zone:* flows in the 40 to 50 percentile range, median stream flow conditions
- *Dry zone:* flows in the 60 to 90 percentile range, related to dry-weather flows
- *Low-flow zone:* flows in the 90 to 100 percentile range, related to drought conditions

For each flow category, an allowable daily load was identified using the median load for that flow range. The allowable load was compared to the existing load to identify necessary load reductions.

Table 8 presents the TMDL allocations establishing using the load duration approach.

Table 8. TMDL Summary for fecal coliform in Carter Creek

Fecal coliform (10^6/day)	TMDL component	High flows 0–10	Moist conditions 10–40	Mid-range flows 40–60	Dry conditions 60–90	Low flows 90–100
	Current Load[1]	298,727	14,298	120	324	95
	TMDL[1] = LA + WLA + MOS	13,897	3,729	1,664	802	411
	LA	12,507	3,356	1,497	722	370
	WLA	0	0	0	0	0
	MOS (10%)	1,390	373	166	80	41
	Load Reduction (%)	**96%**	**77%**	**0%**	**0%**	**0%**

[1]Current load represents median existing load for the respective flow zone. TMDL represents median allowable daily load for the respective flow zone.

Supplementary Data

Because the TMDL analysis used the load duration approach, it is based on the available observed flow and water quality data. Supplementary data are not necessary to develop the daily load dataset for identifying the daily load expression.

Daily Load Dataset

The load duration analysis calculates a series of allowable daily loads using observed flow records and the water quality criterion, providing the daily load dataset.

Crafting the Appropriate Daily Load Expression

The load duration analysis identifies allowable daily loads for five flow categories. However, these loads represent average conditions and are used to identify general load reductions necessary to meet WQS. To supplement the non-daily TMDL allocations, corresponding daily maximum loads should be identified to better gauge instantaneously measured in-stream conditions. For example, while overall load reductions are not identified for the low-flow ranges, the stream does experience occasional elevated bacteria during these times. A daily maximum would provide more confidence in targeting and tracking control of low-flow sources.

Daily Load Expression

The daily load expression for Carter Creek was established as a dynamic, flow-variable daily maximum, as represented by the load duration curve in Figure 19. By setting the daily maximum as a flow-variable value, the expression is consistent with the non-daily TMDL analysis in its intent and underlying data, and the expression inherently accounts for varying source behavior and resulting water quality conditions across the flow conditions. As an alternative presentation to the load duration curve, the corresponding flow and allowable daily load values can be plotted as a rating curve, shown in Figure 20. This graph presents the allowable daily load based on flow magnitude rather than flow frequency. This presentation also provides an equation representing the relationship between flow and daily maximum load to allow for easy calculation of the allowable daily load on the basis of an observed flow value.

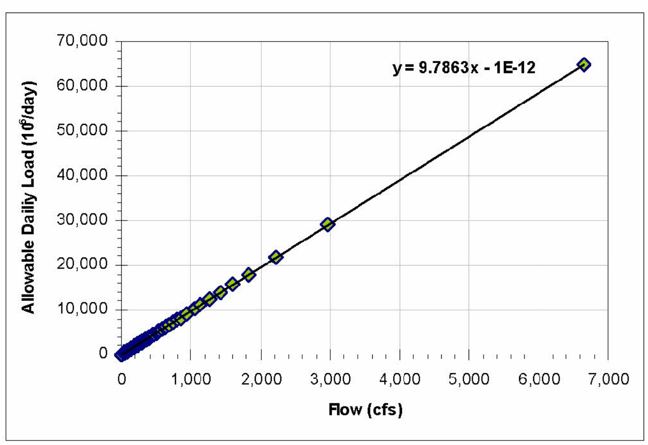

Figure 20. Flow versus daily maximum load.

AR0022572

Example 5: Muddy River Sediment TMDL

Problem Definition

Muddy River was listed as impaired by sediment because of elevated TSS concentrations and expected impairments to benthic communities and aquatic life habitat.

TMDL Technical Approach

The TMDL was developed for using a dynamic watershed model, SWAT, to link watershed sources to in-stream response. The model was used to identify the loading capacity to meet a TSS target established to represent support of designated uses. The target was expressed as a monthly average concentration of 40 mg/L on the basis of historical monitoring data for reference stream reaches and was consistent with available literature on acceptable levels of TSS to support fishery uses. Figure 21 presents the model calibration for hydrology, and Figure 22 presents the model calibration for TSS.

Sources loads were reduced in a variety of management scenarios to select the model scenario that met the established water quality target and represented feasibly source controls.

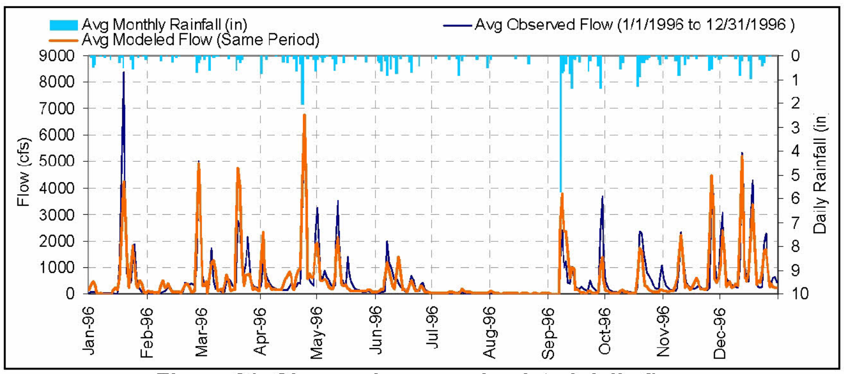

Figure 21. Observed versus simulated daily flow

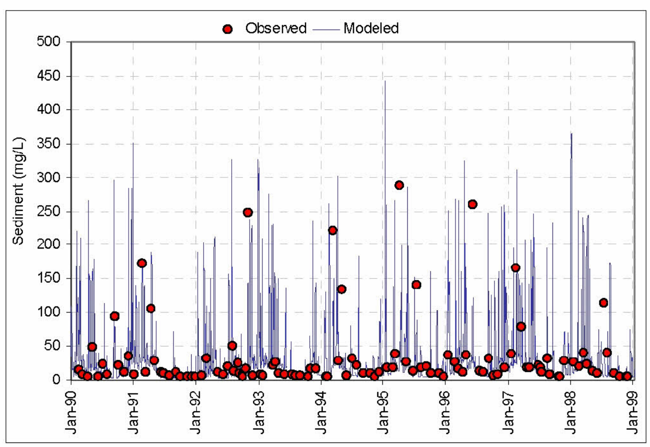

Figure 22. Observed versus simulated TSS.

TMDL Allocation Expression

TMDL allocations were expressed as annual loads that are based on an average annual load over the 15-year simulation period, representing a variety of climatic and source loading conditions. Because in-stream impairment from sediment is a chronic issue with conditions dependent more on cumulative loading than on instantaneous inputs and because nonpoint sources dominate the sediment loading to the river, an annual allocation was appropriate for the TMDL.

Supplementary Data

Because the TMDL analysis used a dynamic model, it produces a time series of allowable daily loads. Supplementary data are not needed to develop the daily load dataset for identifying the daily load expression.

Daily Load Dataset	The modeling analysis provides daily output of simulated loads, providing the daily load dataset.
Crafting the Appropriate Daily Load Expression	Developing the daily load expression for Muddy River is driven primarily by source behavior and times of critical loading. The majority of sediment loading to the river is dependent on precipitation events and resulting erosion and runoff as well as streambank erosion from increased in-stream flows.
Daily Load Expression	To capture the dependency of sediment loading on surface runoff (reflected in-stream by resulting flow conditions), the daily load expression for Muddy River was established as flow-variable targets. Modeled allowable daily loads were arranged according to their corresponding daily flows and the associated flow exceedance percentile. The flows and daily loads were grouped into 10 flow categories using increments of 10-percentile (e.g., 0–10, 10–20). A daily maximum load and daily average load were calculated for each of 10 flow ranges, as shown in Figure 23 and Table 9. Because there was high confidence in the model predictions and the underlying observed dataset, the daily maximum was set at the 99th percentile load for each flow grouping, rather than using a lower, more conservative load.

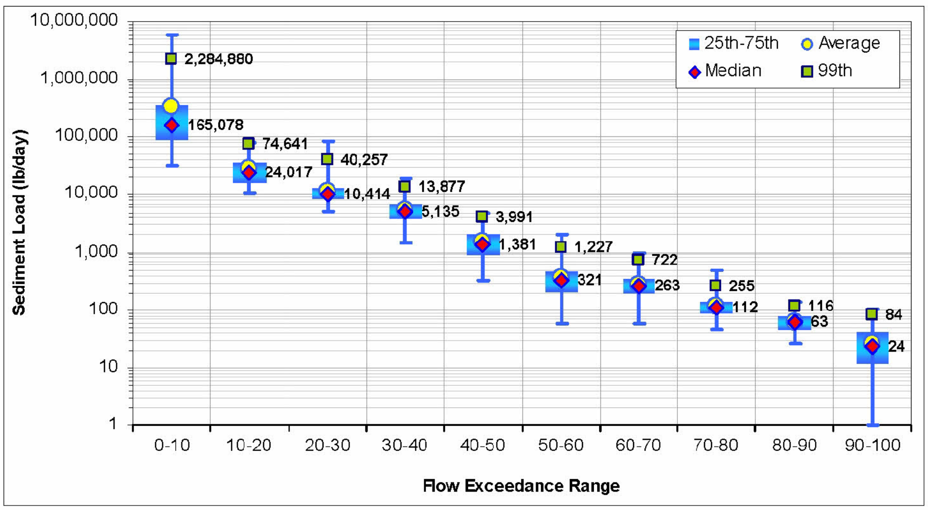

Figure 23. Daily maximum and average allowable loads by month.

Table 9. Daily maximum and average allowable loads by month

Flow exceedance range	Minimum flow in range (ft^3/s)	Maximum flow in range (ft^3/s)	Allowable median load (lb/day)	Allowable daily maximum load (lb/day)
0–10	0.0	3.9	165,078	2,284,880
10–20	3.9	4.8	24,017	74,641
20–30	4.8	6.7	10,414	40,257
30–40	6.7	10.8	5,135	13,877
40–50	10.8	20.7	1,381	3,991
50–60	20.7	39.0	321	1,227
60–70	39.0	75.1	263	722
70–80	75.1	157.9	112	255
80–90	157.9	394.8	63	116
90–100	394.8	4,958.0	24	84

Example 6: Pine Lake Nutrient TMDL

Problem Definition

Pine Lake is impaired due to excessive nutrients. Eutrophic conditions result in frequent algal blooms, which affect water supply intake and recreational uses (e.g., boating, fishing). In addition, increased algal production and subsequent decay of plant matter depletes dissolved oxygen in the lake, impacting the aquatic life uses. No numeric criteria are available for nutrients.

TMDL Technical Approach

The TMDL for Pine Lake was developed for phosphorus using an empirical method to identify allowable input loads. Vollenweider (1975) developed an empirical relationship between areal phosphorus loading and lake residence time and depth to characterize lake trophic status. Figure 24 presents Vollenweider's loading plot, where L_p is the areal loading of total phosphorus in grams per square meter per year (g/m^2/yr), H is mean depth in meters and τ_w is hydraulic residence time in years.

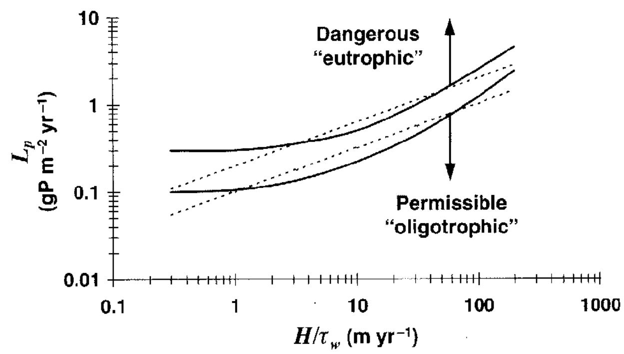

Figure 24. Vollenweider loading plot.

The allowable loading rate for Pine Lake was identified to represent the middle of the mesotrophic boundary (between eutrophic and oligotrophic). Using the lake's mean depth and hydraulic residence time identified an allowable average annual areal loading rate of 2.7 g/m^2/yr. Multiplying that rate by the lake's surface area of 300 acres (1,214,100 m^2) results in an allowable annual phosphorus load of 1,821,150 g/yr or 4,015 lb/yr.

TMDL Allocation Expression

TMDL allocations were expressed as allowable annual phosphorus loads. The loading capacity was calculated on the basis of the allowable loading rate identified using the Vollenweider relationship. Existing loads to the lake were calculated using export coefficients found in available literature for watershed land uses for nonpoint sources and using available discharge flow and concentration data for point sources. The existing load was compared to the allowable load to identify necessary load reductions, which were then distributed among targeted sources to identify source allocations, also expressed as annual loads.

Supplementary Data

Very limited recent water quality, loading, or inflow data are available for Pine Lake. Very few in-lake water quality data points exist within the past two decades, and no flow data are available for the surrounding watershed.

Daily Load Dataset

Sufficient flow data are not available to support distributing the annual loading capacity for Pine Lake. In addition, because the area that drains directly to the lake (rather than through tributary inflows) is approximately 40 percent of the drainage area, using tributary flows to distribute the allowable load could produce misleading results. Precipitation data could be used to distribute the annual load over a determined time frame; however, distributing the annual load developed with an empirical method into daily loads using precipitation data would force an inappropriate level of resolution on the approach. Therefore, a statistical approach will be used to identify a maximum daily load corresponding to the allowable average annual load.

Crafting the Appropriate Daily Load Expression	EPA's *Technical Support Document for Water Quality Based Toxics Control* (USEPA 1991), referred to as the TSD, provides a method for identifying a maximum daily limit that is based on a long-term average and considering variation in a dataset. The method is represented by the following equation $MDL = LTA \times e^{[z\sigma - 0.5\sigma^2]}$ where *MDL* = maximum daily limit *LTA* = long-term average *z* = z statistic of the probability of occurrence $\sigma^2 = \ln(CV^2+1)$ *CV* = coefficient of variation
Daily Load Expression	The daily load expression is identified as a static daily maximum load, calculated using the method in the TSD for identifying maximum daily limits that are based on long-term averages. Assuming a probability of occurrence of 95 percent and a CV of 0.3 (based on available data), the maximum daily load corresponding to the average annual load of 4,015 lb/yr (and average daily load of 11 lb/day) is 17 lb/day.
References	USEPA (U.S. Environmental Protection Agency). 1991. *Technical Support Document for Water Quality-based Toxics Control*. EPA 440/4-91-001. U.S. Environmental Protection Agency, Office of Water, Washington, DC. Vollenweider, R.A. 1975. Input-Output Models with Special Reference to the Phosphorus Loading Concept in Limnology. *Schweiz. Z. Hydrol.* 37:53–84.

Example 7: Anacostia River TSS TMDL

Problem Definition

In 1998 the District of Columbia (DC) listed the Anacostia River as impaired by TSS, biochemical oxygen demand, bacteria, organics, metals, and oil and grease. And Maryland has placed the Anacostia River on its 303(d) list as impaired by nutrients (1996), sediments (1996), fecal bacteria–nontidal waters (2002), impacts to biological communities (2002), toxics–PCBs (2002), toxics–heptachlor epoxide (2002) and fecal bacteria–tidal waters (2004).

A TSS TMDL was calculated for the Tidal Anacostia in DC in 2002; it was replaced by a watershed-wide TMDL in 2007 in which maximum daily loads for each source category were calculated.

Table 10. Water quality standards

Jurisdiction	Tidal	Nontidal
Maryland	*TSS*—From April 1 to Oct. 31, seasonal secchi application depth ≥ 0.4 m.	Narrative based on protection of aquatic life uses
District of Columbia	*TSS*—From April 1 to Oct. 31, seasonal average secchi depth ≥ 0.8 m *Chlorophyll* a—July 1 to September 30, seasonal average = 25 µg/L	Narrative based on protection of aquatic life uses

TMDL Technical Approach

The modeling framework used for the TMDL analysis was a linked watershed/hydrodynamic/water quality model, an application of the USGS ESTIMATOR model and a reference approach for sediment endpoints. The watershed model, HSPF, was linked to a customized hydrodynamic and water quality model, Tidal Anacostia Model (TAM)/WASP. Results from the ESTIMATOR model were used to calibrate the watershed model.

The modeling application developed for the TMDL analysis simulates daily values of both total suspended sediment concentrations and water clarity on the basis of various inputs including: information on tides, precipitation, and tributary flows; daily estimates of sediment loads from the various sources; DC's MS4s; and CSOs from DC's combined storm sewer and sanitary sewer system (CSS).

TMDL Allocation Expression

In the TMDL, the 3-year time period 1995–1997 was chosen as the simulation period for load reduction scenarios to meet tidal water clarity criteria. This period was selected because it represents a relatively dry year, wet year, and average year, according to precipitation data. The TMDL was calculated as a seasonal average load and was based on the most critical loading period from that 3-year period (i.e., the highest single daily loading predicted during the 3-year period).

The sediment TMDLs for both Maryland and DC tidal and nontidal waters of the Anacostia River are 7097.6 tons/year annually and 3396.1 tons/growing season for the growing season from April 1 to October 31.

Supplementary Data

No additional data were required to develop the daily load dataset; however, model output was processed and provided in spreadsheet format for the conversion to daily loads. Observed flow data for the Anacostia River were included in the spreadsheet for each day as well.

Daily Load Dataset

Modeled daily TSS loading rates for the period 1995–1997 consistent with the annual/seasonal TMDL loads were provided in a spreadsheet format for the following sources:

Table 11. Sources in the Anacostia TMDL analysis

Nontidal Anacostia	Tidal-Anacostia
Maryland MS4 DC MS4 Maryland Other Point Sources DC Other Point Sources Maryland Nonpoint Sources DC Nonpoint Sources	Maryland MS4 Maryland Nonpoint Sources DC Upper Anacostia MS4 DC Lower Anacostia MS4 DC Lower Anacostia CSO DC Upper Anacostia CSO DC Lower Anacostia Other Point Sources

Crafting the Appropriate Daily Load Expression

The factors and key issues considered in identifying the appropriate daily load expression include the following:

- *Non-daily TMDL Allocation Expression*—allocations were expressed on a seasonal basis.
- *Source Types*—sources of sediment in the Anacostia River watershed are mainly nonpoint sources and include sediment from historical land activities (clearing of forests), surface mining and construction as well as general nonpoint source runoff from urban areas. Streambank and stream channel erosion is believed to be the largest significant source of sediment in the watershed. Tidal resuspension of bed sediment is also included in the list of nonpoint sources of sediment in the watershed. Point sources include the MS4s of Montgomery and Prince George's Counties and DC, multiple NPDES permitted municipal and industrial facilities, as well as multiple CSO discharges.
- *Source Behavior*— Because of the urban nature of the watershed, natural hydrologic functions of the Anacostia River and its tributaries have been significantly altered. Precipitation flowing over land surfaces causes soil to be eroded and carried into nearby streams either directly or through storm sewers. The altered urban hydrology causes atypically high flows in streams during storms, and atypically low flows during dry periods. The high flows occurring during storm events cause excessive erosion of streambanks and streambeds, leading to the degraded stream channel conditions that can be observed in many areas of the Anacostia watershed today. The high storm flows transport this eroded sediment downstream to the main tributaries and, eventually, to the tidal Anacostia River.
- *Flow Variation*— with the exception of the Other Point Sources in the watershed, all major source categories are associated with precipitation and runoff events and, thus, higher flow conditions. The critical condition for water clarity in the tidal Anacostia is the occurrence of high-flow events, which cause tributaries and storm sewers to discharge large amounts of sediment into the tidal river.

Daily Load Expression

Load duration analysis was performed on the time series for each pollutant source and daily maximums were identified to accompany the long-term LA. The daily load expressions developed for the Anacostia River TSS TMDL apply separate methods for unique source categories. Separate approaches were used to identify the maximum daily load expression for MS4s and nonpoint sources, CSOs, and for other point sources.

Table 12. Daily Load expression option used for each source

	MS4 and NPS	CSO	Other point source
Tidal	Single Load	Single Load	Single Load (TSD)
Nontidal	Flow variable	NA	Single Load (TSD)

Nontidal MS4 and NPS:

- Conducted flow duration analysis with daily loading times series over the simulation period (1995–1997) for each contributing source. Divided flows into five strata corresponding to quintiles (< 20%, 20–40%, 40–60%, 60–80%, > 80%).
- Determined maximum daily TSS load over the simulation period for each source and for each quintile.
- Applied the maximum daily load identified in the step above as the basis of the maximum daily load expression for each source.

Tidal MS4 and NPS

- Used the TMDL condition daily loading time series for the simulation period for each source
- Determined the maximum daily TSS load for the period for each source
- Applied the maximum daily load identified in the step above as the basis of the maximum daily load expression for each source

CSOs

- Used the TMDL condition daily loading time series for the simulation period for each CSO source

- Separated the contributing CSO discharges into two categories: DC Tidal Upper Anacostia and DC Tidal Lower Anacostia.
- Summed the contributing CSO daily loading time series within these two categories - DC Tidal Upper Anacostia and DC Tidal Lower Anacostia.
- Determined the average and maximum daily TSS loads over this period of simulation for the DC Tidal Upper Anacostia and DC Tidal Lower Anacostia.
- Applied the maximum and average daily load obtained in the step above as the basis for the maximum daily load expression for each source.

Other point sources

- Used the TMDL condition daily loading time series for the simulation period for each other point source.
- Converted these values, where necessary, from long-term averages to maximum daily loads by multiplying them by a factor of 3.11 (from TSD Table 5-2). To meet the WLA, compliance with the long-term average loads is also necessary.

Note: The following daily loads are DRAFT and have not been approved by EPA. Annually Based and Seasonally Based Maximum Daily Loads were developed. Below, the Seasonally Based Maximum Daily Loads are presented.

Seasonally Based Maximum Daily Loads

Table 13. Nontidal Anacostia (MS4, NPS, Other PS)

Flow range (m^3/s)	MD Nontidal MS4-WLA	DC Nontidal MS4-WLA	MD Nontidal Other PS-WLA	DC Nontidal Other PS-WLA
< 0.98	0.24	0.03	0.618	0.0066
0.98–1.79	1.20	0.12	0.618	0.0066
1.79–2.71	0.48	0.05	0.618	0.0066
2.71–4.54	9.88	0.77	0.618	0.0066
> 4.54	274.46	20.20	0.618	0.0066

Table 14. Nontidal Anacostia (MS4, NPS, Other PS)

Flow range (m^3/s)	MD Nontidal LA	DC Nontidal LA	Nontidal TMDL
< 0.98	0.27	0.01	0.75
0.98–1.79	1.38	0.04	2.94
1.79–2.71	0.66	0.02	1.41
2.71–4.54	11.00	0.24	22.10
> 4.54	1,124.84	0.84	1,420.54

Table 15. Tidal—MD (all flow ranges)

Background	MD Tidal MS4-WLA	MD Tidal LA	TMDL to MD/DC Border
1420.54	18.85	0.0005	1,439.39

Table 16. Tidal—DC Upper Anacostia (all flow ranges)

Background	DC Upper Anacostia MS4-WLA	DC Upper Anacostia CSO-WLA	DC Upper Anacostia LA	TMDL to Upper / Lower Boundary
1,439.39	24.68	84.61 (max) 21.94 (avg)	--	1,548.67

Table 17. Tidal—DC Lower Anacostia (all flow ranges)

Background	DC Lower Anacostia MS4-WLA	DC Lower Anacostia Other PS-WLA	DC Lower Anacostia CSO-WLA	DC Lower Anacostia LA	Total TMDL
1,548.67	14.76	0.0043	67.10 (max) 25.85 (avg)	-	1,630.54

References

USEPA (U.S. Environmental Protection Agency). 1991. *Technical Support Document for Water Quality-based Toxics Control*. EPA 440/4-91-001. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

ICPRB (Interstate Commission on the Potomac River Basin). 2007. *DRAFT Report: Total Maximum Daily Loads of Sediment/Total Suspended Solids for the Anacostia River Basin, Montgomery and Prince George's Counties, Maryland and The District of Columbia*. Prepared for U.S. Environmental Protection Agency Region 3, Watershed Protection Division, by Interstate Commission on the Potomac River Basin, Rockville, MD.

Appendix B: Identifying Daily Expressions for Non-daily Concentration-based TMDLs

Some TMDLs rely on establishing a concentration-based loading capacity, often equivalent to an applicable numeric water quality criterion. As with load-based TMDLs, if the established concentration-based TMDL is not on a daily time step, the TMDL should also include a daily expression representing the non-daily allocation. This appendix presents an approach for identifying a daily expression corresponding to the non-daily allocations developed in concentration-based TMDLs.

Numeric water quality standards or other water quality targets (representing narrative water quality criteria) have a duration component. For some criteria or targets, the duration is expressed as a daily average or *never to exceed* value. As an example, waters designated for support of semi-permanent, warm-water fish life in South Dakota must not exceed a daily maximum of 158 mg/L TSS. For concentration-based TMDLs established to meet these targets, the TMDL is already expressed on a daily basis. However, many water quality criteria or representative TMDL targets are based on longer time steps, including monthly or even annual averages. Figure 25 illustrates an example TMDL developed to attain the water quality criterion of an annual average concentration of 25 mg/L TSS. For concentration-based TMDLs set equivalent to longer-term targets, the TMDLs should also include a daily expression.

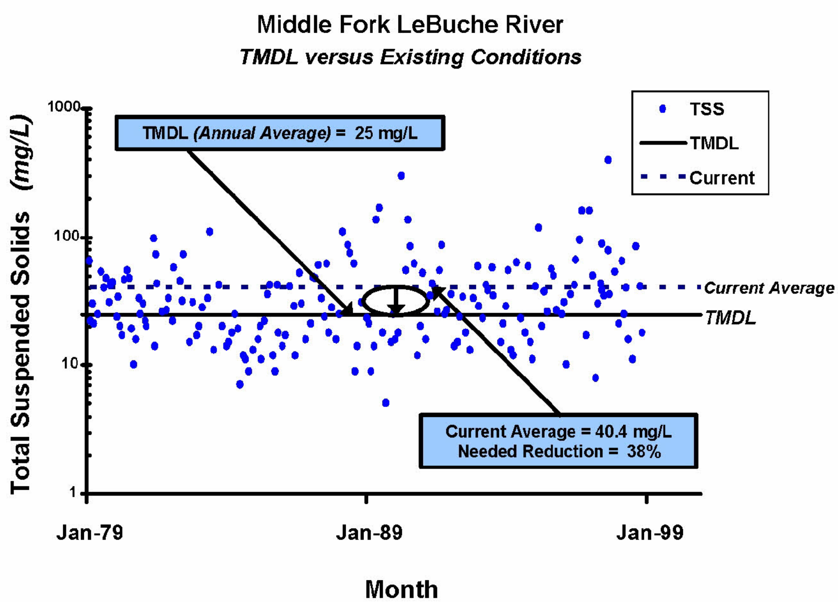

Figure 25. Example of a concentration-based TMDL.

The daily expression representing the non-daily concentration-based TMDL should account for variability occurring in the system. Water quality and quantity vary over time in terms of volumes discharged and constituent concentrations. Variations occur because of a number of factors, including changes in weather conditions, precipitation, seasonality, and source inputs. Figure 25 shows how concentrations vary for a parameter when water quality data are plotted against time.

Understanding the variability associated with water quality conditions is a key part of evaluating an impaired waterbody. Water quality at a location over time can be described using common descriptive statistics, such as the monthly or annual average concentration, the standard deviation, and the coefficient of variation. The coefficient of variation is a statistical measure of the relative variability of a dataset and is defined as the ratio of the standard deviation to the mean. Another way to describe water quality patterns is by constructing a *frequency-concentration* plot of the data. Figure 26, for example, depicts the Middle Fork LeBuche TMDL with a frequency-concentration plot of data that reflects attainment of water quality standards.

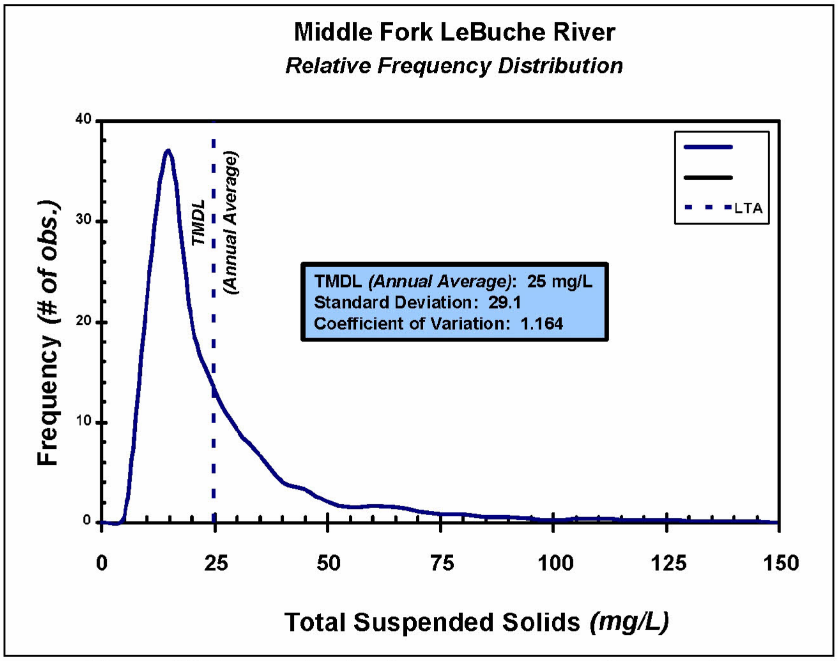

Figure 26. Example of a frequency-concentration plot.

On the basis of the frequency-concentration curve's shape, data can be described in terms of a particular type of statistical distribution. Choices often include a normal distribution (bell-shaped), lognormal distribution (positively skewed), or other variations on the lognormal distribution. EPA's *Technical Support Document for Water Quality-Based Toxics Control* (USEPA 1991) uses lognormal distributions to determine maximum daily and monthly average effluent limits, based on achieving a long-term average (LTA) target and an understanding of variability.

The TSD provides a statistical framework to identify a target maximum daily concentration corresponding to an LTA and based on a coefficient of variation and the assumption of a lognormal distribution. The equation for determining the maximum daily limit (MDL) is as follows (USEPA 1991):

$$MDL = LTA \times e^{[z\sigma - 0.5\sigma^2]},$$

where

MDL = Maximum daily limit
LTA = Long-term average (in the same units as the MDL)
Z = z-score associated with target recurrence interval
$\sigma^2 = \ln(CV^2 + 1)$
CV = Coefficient of variation

Details regarding the mathematics used to derive this equation are described in USEPA (1991).

The z-score is sometimes called the *standard score* for normal distributions because it provides a useful way to compare sets of data with different means and standard deviations. The z-score for an item (or a particular recurrence interval) indicates how far and in what direction that item deviates from its distribution's mean (expressed in units of its distribution's standard deviation). For instance, a z-score of +1.0 indicates that item (or recurrence interval) is one standard deviation in the positive direction from the mean. Z-scores are published in basic statistical reference tables and are often included as a spreadsheet function (e.g., NORMSINV(y) in Microsoft Excel).

Using this relationship, the TSD includes a table of *LTA to MDL* multipliers for several recurrence interval/coefficient of variation combinations (USEPA 1991). Table 18 provides a summary of these multiplier values for several averaging periods used in TMDL development (e.g., 30-day, 60-day …365-day). These averaging periods are also expressed as a recurrence interval to identify the appropriate z-score for use in the equation. For example, the daily maximum of a 30-day averaging period equates to a 96.8 percent recurrence interval (e.g., [30/31]% or [k/k+1]% where k is the number of averaging period days) with a corresponding z-score of 1.849. If the coefficient of variation for a parameter is 1.0, the multiplier to convert the LTA to an MDL is 3.30 (**Note**: key boxes for this combination are shaded in Table 18).

Table 18. Multipliers used to convert an LTA to MDL

Averaging period (days)	Recurrence interval	Z-score	Coefficient of variation								
			0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8
30	96.8%	1.849	1.41	1.89	2.39	2.87	3.30	3.67	3.99	4.26	4.48
60	98.4%	2.135	1.50	2.11	2.80	3.50	4.18	4.81	5.37	5.87	6.32
90	98.9%	2.291	1.54	2.24	3.05	3.91	4.76	5.57	6.32	7.00	7.62
120	99.2%	2.397	1.58	2.34	3.24	4.21	5.20	6.16	7.06	7.89	8.66
180	99.4%	2.541	1.62	2.47	3.51	4.66	5.87	7.06	8.20	9.29	10.3
210	99.5%	2.594	1.64	2.52	3.61	4.84	6.13	7.42	8.67	9.86	11.0
365	99.7%	2.778	1.70	2.71	4.00	5.51	7.15	8.83	10.5	12.13	13.7

Figure 27 graphically illustrates a *log probability plot* of the EPA equation using data that reflect conditions associated with attainment of the water quality standards. The x-axis is expressed as the z-score of a normal probability distribution; the y-axis displays concentrations on a logarithmic scale. A probability plot is one method that can be used to check the assumption of lognormality. If the data follow the pattern of a lognormal distribution, they will fall approximately along a straight line, as shown in Figure 27.

Figure 27 also shows translation of the recurrence interval for an annual averaging period (e.g., 365 days) to the corresponding maximum daily concentration limit. The following calculations demonstrate identification of the MDL on the basis of the corresponding LTA:

$$MDL = LTA \times e^{[z\sigma - 0.5\sigma^2]},$$

where

$LTA = 25$ mg/L

$z = 2.778$ (based on recurrence interval of 99.7%)

$CV = 1.164$

$$\sigma^2 = \ln(CV^2 + 1) = \ln(1.164^2 + 1) = 0.857$$

Therefore,

$$MDL = 25\frac{mg}{L} \times e^{[2.778 \times 0.926 - 0.5 \times 0.857]} = 25\frac{mg}{L} \times 8.533 = 213.3\frac{mg}{L}.$$

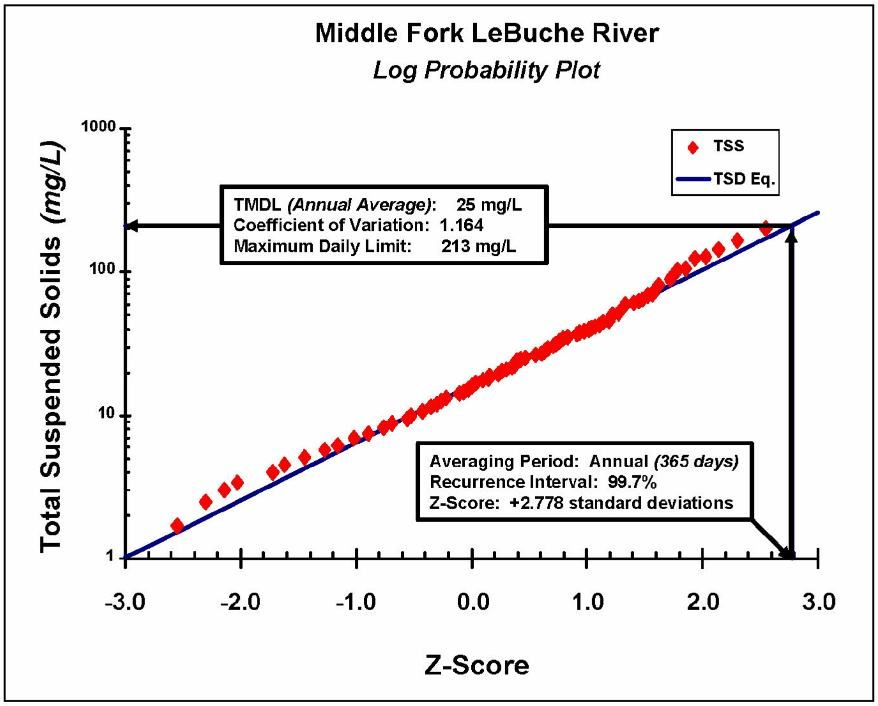

Figure 27. Log probability display.